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# **REPORT 1135**

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## **EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW**

**By AMES RESEARCH STAFF**

**Ames Aeronautical Laboratory  
Moffett Field, Calif.**

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I

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# REPORT 1135

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW<sup>1</sup>

By AMES RESEARCH STAFF

### SUMMARY

This report, which is a revision and extension of NACA TN 1428, presents a compilation of equations, tables, and charts useful in the analysis of high-speed flow of a compressible fluid. The equations provide relations for continuous one-dimensional flow, normal and oblique shock waves, and Prandtl-Meyer expansions for both perfect and imperfect gases. The tables present useful dimensionless ratios for continuous one-dimensional flow and for normal shock waves as functions of Mach number for air considered as a perfect gas. One series of charts presents the characteristics of the flow of air (considered a perfect gas) for oblique shock waves and for cones in a supersonic air stream. A second series shows the effects of caloric imperfections on continuous one-dimensional flow and on the flow through normal and oblique shock waves.

### INTRODUCTION

The practical analysis of compressible flow involves frequent application of a few basic results. A convenient compilation of equations, tables, and charts embodying these results is therefore of great assistance in both research and design. The present report makes one of the first such compilations (ref. 1) more readily available in a revised and extended form. The revisions include a complete rewriting of the lists of equations, as well as the correction of certain typographical errors which appeared in the earlier work. The extensions are primarily in the directions dictated by increasing flight speeds, that is, to higher Mach numbers and to higher temperatures with the accompanying gaseous imperfections.

Compilations similar to those of reference 1 have been given in other publications, as, for example, references 2 through 6. These references have been utilized in extending the tables and charts to higher values of the Mach number. The extension to imperfect gases is based on the relations presented in references 7 and 8.

### SYMBOLS AND NOTATION

#### PRIMARY SYMBOLS

speed of sound

cross-sectional area of stream tube or channel

$C_N$	normal-force coefficient for cones, $\frac{\text{normal force}}{q_\infty S_b}$
$c_p$	specific heat at constant pressure
$c_v$	specific heat at constant volume
$h$	enthalpy per unit mass, $u + pv$
$l$	characteristic reference length
$M$	Mach number, $\frac{V}{a}$
$p$	pressure <sup>2</sup>
$q$	dynamic pressure, $\rho V^2/2$
$q$	heat added per unit mass
$R$	gas constant
$R$	Reynolds number, $\frac{\rho V l}{\mu}$
$S_b$	base area of cone
$s$	entropy per unit mass
$T$	absolute temperature <sup>2</sup>
$u$	internal energy per unit mass
$v$	specific volume, $\frac{1}{\rho}$
$u, v$	velocity components parallel and perpendicular respectively, to free-stream flow direction
$\bar{u}, \bar{v}$	velocity components normal and tangential, respectively, to oblique shock wave
$V$	speed of flow
$V_m$	maximum speed obtainable by expanding to zero absolute temperature
$w$	external work performed per unit mass
$\alpha$	angle of attack
$\beta$	$\sqrt{ M^2 - 1 }$
$\gamma$	ratio of specific heats, $\frac{c_p}{c_v}$
$\delta$	angle of flow deflection across an oblique shock wave
$\theta$	shock-wave angle measured from upstream flow direction
$\Theta$	molecular vibrational-energy constant
$\mu$	Mach angle, $\sin^{-1} \frac{1}{M}$
$\mu$	absolute viscosity
$\nu$	Prandtl-Meyer angle (angle through which a supersonic stream is turned to expand from $M=1$ to $M>1$ )

<sup>1</sup>Supersedes NACA TN 1428, "Notes and Tables for Use in the Analysis of Supersonic Flow" by the Staff of the Ames 1- by 3-foot Supersonic Wind-Tunnel Section, 1947.

<sup>2</sup>When used without subscripts,  $p$ ,  $\rho$ , and  $T$  denote static pressure, static density, and static temperature, respectively.

$\xi$	pressure ratio across a shock wave, $\frac{p_2}{p_1}$
$\rho$	mass density <sup>2</sup>
$\sigma$	semivertex angle of cone
SUBSCRIPTS	
$\infty$	free-stream conditions
$1$	conditions just upstream of a shock wave
$2$	conditions just downstream of a shock wave
$t$	total conditions (i. e., conditions that would exist if the gas were brought to rest isentropically)
*	critical conditions (i. e., conditions where the local speed is equal to the local speed of sound)
$c$	conditions on the surface of a cone
$r$	reference (or datum) values
perf	quantity evaluated for a gas which is both thermally and calorically perfect
therm perf	quantity evaluated for a gas which is thermally perfect but calorically imperfect
( $)_p$	derivative evaluated at constant pressure
( $)_s$	derivative evaluated at constant entropy
( $)_T$	derivative evaluated at constant temperature
( $)_v$	derivative evaluated at constant specific volume
( $)_{re}$	quantity evaluated over a reversible path

## NOTATION

The notation in brackets [ ] after many of the equations signifies that the equation is valid only within certain limitations. For example:

[perf]	means that the equation is restricted to a gas which is both thermally and calorically perfect. (By "thermally perfect" it is meant that the gas obeys the thermal equation of state $p = \rho RT$ . By "calorically perfect" it is meant that the specific heats $c_p$ and $c_v$ are constant.)
[therm perf]	means that the only restriction on the gas is that it must be thermally perfect. Equations so marked may be used for calorically imperfect gases. (They are, of course, also valid for completely perfect gases.)
[isen]	means that the flow process must take place isentropically. Equations so marked may not be applied to the flow across a shock wave.
[adiab]	means that the only restriction on the flow process is that it must take place adiabatically—that is, without heat transfer. (Such a flow process may or may not be isentropic depending on whether it is or is not reversible.) Equations so marked may be applied to the flow across a shock wave.

An equation without notation has no restrictions beyond those basic to the study of thermodynamics and/or inviscid compressible flow.

## FUNDAMENTAL RELATIONS

## THERMODYNAMICS

## THERMAL EQUATIONS OF STATE

A thermal equation of state is an equation of the form

$$p = p(v, T) \quad (1)$$

Several of the more commonly used thermal equations of state are the following:

Equation for thermally perfect gas

$$p = \frac{RT}{v} = \rho RT \quad [\text{therm perf}] \quad (2)$$

or

$$\frac{dp}{p} - \frac{dp}{\rho} - \frac{dT}{T} = 0 \quad [\text{therm perf}] \quad (3)$$

Equations for thermally imperfect gas

Van der Waals' equation (ref. 9)

$$p = \frac{RT}{v-b} - \frac{a}{v^2} \quad (4)$$

where  $a$  is the intermolecular-force constant and  $b$  the molecular-size constant (see ref. 9, pp. 390 et seq. for numerical values).

Berthelot's equation (ref. 7)

$$p = \frac{RT}{v-b} - \frac{c}{v^2} \quad (5)$$

where  $b$  is the molecular-size constant and  $c$  is the intermolecular-force constant (see ref. 7 for numeric values).

Beattie-Bridgeman equation (ref. 10)

$$p = \frac{RT}{v^2} \left( 1 - \frac{c}{vT^2} \right) \left[ v + B_0 \left( 1 - \frac{b}{v} \right) \right] - \frac{A_0}{v^2} \left( 1 - \frac{a}{v} \right) \quad (6)$$

where  $a$ ,  $A_0$ ,  $b$ ,  $B_0$ , and  $c$  are constants for a given gas (see ref. 10, p. 270 for numerical values).

## CALORIC EQUATION OF STATE

A caloric equation of state is an equation of the form

$$u = u(v, T) \quad (7)$$

It can be shown that

$$du = c_v dT + \left[ T \left( \frac{\partial p}{\partial T} \right)_v - p \right] dv \quad (8)$$

$$du = c_v dT \quad [\text{therm perf}] \quad (8)$$

If the gas is calorically perfect—that is, the specific heats are constant—equation (8b) can be integrated to obtain

$$u = c_v T + u_0, \quad [\text{perf}] \quad (9)$$

<sup>2</sup> When used without subscripts,  $p$ ,  $\rho$ , and  $T$  denote static pressure, static density, and static temperature, respectively.

## ENERGY RELATIONS

The law of conservation of energy gives

$$\left. \begin{aligned} dq &= du + dw \quad (\text{first law of thermodynamics}) \\ &= du + p dr = dh + v dp \end{aligned} \right\} \quad (10a)$$

$$\left. \begin{aligned} dq &= c_v dT + p dr \\ &= c_p dT - v dp \end{aligned} \right\} \quad [\text{therm perf}] \quad (10b)$$

## SPECIFIC HEATS

The specific heats at constant pressure and constant volume are defined by

$$c_p \equiv \left( \frac{\partial q}{\partial T} \right)_p = \left( \frac{\partial h}{\partial T} \right)_p \quad (11)$$

$$c_v \equiv \left( \frac{\partial q}{\partial T} \right)_v = \left( \frac{\partial u}{\partial T} \right)_v \quad (12)$$

It can be shown that

$$c_p - c_v = \left[ \left( \frac{\partial u}{\partial v} \right)_T + p \right] \left( \frac{\partial v}{\partial T} \right)_p = -T \frac{\left( \frac{\partial p}{\partial T} \right)_v^2}{\left( \frac{\partial v}{\partial T} \right)_p} \quad (13a)$$

$$c_p - c_v = R \quad [\text{therm perf}] \quad (13b)$$

The ratio of specific heats is defined as

$$\gamma \equiv \frac{c_p}{c_v} \quad (14)$$

According to the kinetic theory of gases, for many gases over a moderate range of temperature,

$$\gamma = \frac{n+2}{n} \quad (15)$$

where  $n$  is the number of effective degrees of freedom of the gas molecule. Useful relations for thermally perfect gases are

$$c_p = \frac{dh}{dT} = c_v + R = \frac{\gamma R}{\gamma - 1} \quad [\text{therm perf}] \quad (16)$$

$$c_v = \frac{du}{dT} = c_p - R = \frac{R}{\gamma - 1} \quad [\text{therm perf}] \quad (17)$$

## ENTHALPY

The enthalpy of a gas is defined by

$$h \equiv u + pr \quad (18)$$

It follows that

$$\begin{aligned} dh &= du + p dr + v dp = dq + v dp \\ &= \left[ c_v + r \left( \frac{\partial p}{\partial T} \right)_v \right] dT + \left[ r \left( \frac{\partial p}{\partial v} \right)_T + T \left( \frac{\partial p}{\partial T} \right)_v \right] dr \end{aligned} \quad (19a)$$

$$dh = (c_v + R) dT = c_p dT \quad [\text{therm perf}] \quad (19b)$$

$$h = (c_v + R) T - u = c_p T + u, \quad [\text{perf}] \quad (20)$$

## ENTROPY

The entropy is defined by

$$ds \equiv \left( \frac{dq}{T} \right)_{rev} \quad (21)$$

It follows that

$$ds = \left( \frac{du + dw}{T} \right)_{rev} = \left( \frac{du + p dr}{T} \right)_{rev} = c_v \frac{dT}{T} + \left( \frac{\partial p}{\partial T} \right)_v dr \quad (22a)$$

$$\left. \begin{aligned} ds &= c_v \frac{dT}{T} + R \frac{dr}{r} \\ &= c_v \frac{dT}{T} - R \frac{dp}{\rho} \\ &= c_p \frac{dT}{T} - R \frac{dp}{p} \\ &= c_v \frac{dp}{p} - c_p \frac{dp}{\rho} \end{aligned} \right\} \quad [\text{therm perf}] \quad (22b)$$

$$\left. \begin{aligned} s - s_r &= c_v \ln \frac{T}{T_r} - R \ln \frac{\rho}{\rho_r} \\ &= c_p \ln \frac{T}{T_r} - R \ln \frac{p}{p_r} \\ &= c_v \ln \frac{p}{p_r} - c_p \ln \frac{\rho}{\rho_r} \end{aligned} \right\} \quad [\text{perf}] \quad (23a)$$

$$\left. \begin{aligned} s - s_r &= c_v \ln \frac{T/T_r}{(\rho/\rho_r)^{\gamma-1}} \\ &= c_p \ln \frac{T/T_r}{(p/p_r)^{(\gamma-1)/\gamma}} \\ &= c_v \ln \frac{p/p_r}{(\rho/\rho_r)^\gamma} \end{aligned} \right\} \quad [\text{perf}] \quad (23b)$$

$$\frac{p}{\rho^\gamma} = \frac{p_r}{\rho_r^\gamma} e^{(s-s_r)/c_v} \quad [\text{perf}] \quad (24)$$

The second law of thermodynamics requires that

$$s - s_r \geq 0 \quad [\text{adiab}] \quad (25)$$

## CONTINUOUS ONE-DIMENSIONAL FLOW

## BASIC EQUATIONS AND DEFINITIONS

The basic equations for the continuous flow of an inviscid non-heat-conducting gas along a streamline are as follows:

Thermal equation of state

$$\frac{p}{\rho} = RT \quad [\text{therm perf}] \quad (26)$$

Dynamic equation

$$\frac{1}{\rho} dp + V dV = 0 \quad (27)$$

Energy equation

$$\left. \begin{aligned} du + d\left(\frac{p}{\rho}\right) + VdV &= 0 \\ dh + VdV &= 0 \end{aligned} \right\} \quad [\text{abiab}] \quad (28a)$$

$$\left. \begin{aligned} c_p dT + VdV &= 0 \\ \frac{\gamma}{\gamma-1} d\left(\frac{p}{\rho}\right) + VdV &= 0 \end{aligned} \right\} \quad [\text{adiab, therm perf}] \quad (28b)$$

Additional useful variables are defined as follows:

Speed of sound

$$a = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s} = \sqrt{\gamma \left(\frac{\partial p}{\partial \rho}\right)_r} \quad (29a)$$

$$= \sqrt{\gamma \frac{p}{\rho}} = \sqrt{\gamma RT} \quad [\text{therm perf}] \quad (29b)$$

$$\approx 49.0 \sqrt{T} \text{ ft/sec for air} \\ \text{if } T \text{ is in degrees Rankine} \\ (= \text{degrees Fahrenheit} + 459.6) \quad (29c)$$

Mach number

$$M = \frac{V}{a} \quad (30)$$

Dynamic pressure

$$q = \frac{1}{2} \rho V^2 \quad (31a)$$

$$= \frac{\gamma}{2} p M^2 \quad [\text{therm perf}] \quad (31b)$$

#### INTEGRATED FORMS OF ENERGY EQUATION

The energy equation (28) can be integrated at once to obtain

$$h + \frac{V^2}{2} = \text{constant} = h_i \quad [\text{adiab}] \quad (32a)$$

$$\left. \begin{aligned} c_p T + \frac{V^2}{2} &= c_p T_i \\ \frac{\gamma}{\gamma-1} \left(\frac{p}{\rho}\right) + \frac{V^2}{2} &= \frac{\gamma}{\gamma-1} \left(\frac{p_i}{\rho_i}\right) \\ \frac{a^2}{\gamma-1} + \frac{V^2}{2} &= \frac{a_i^2}{\gamma-1} \\ \frac{a^2}{\gamma-1} + \frac{V^2}{2} &= \frac{1}{2} \left(\frac{\gamma+1}{\gamma-1}\right) a_*^2 \\ \frac{a^2}{\gamma-1} + \frac{V^2}{2} &= \frac{V_m^2}{2} \end{aligned} \right\} \quad [\text{adiab, perf}] \quad (32b)$$

The three reference speeds  $a_i$ ,  $a_*$ , and  $V_m$  are related by

$$\left. \begin{aligned} \left(\frac{a_i}{a_*}\right)^2 &= \frac{\gamma+1}{2} \\ \left(\frac{V_m}{a_*}\right)^2 &= \frac{\gamma+1}{\gamma-1} \\ \left(\frac{V_m}{a_i}\right)^2 &= \frac{2}{\gamma-1} \end{aligned} \right\} \quad [\text{adiab, perf}] \quad (33)$$

#### PRESSURE-DENSITY RELATION

From equations (27) and (28b) it follows that

$$\frac{p}{\rho^\gamma} = \text{constant} = \frac{p_i}{\rho_i^\gamma} \quad [\text{isen, perf}] \quad (34)$$

from which

$$\frac{p}{p_i} = \left(\frac{\rho}{\rho_i}\right)^\gamma = \left(\frac{T}{T_i}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{a}{a_i}\right)^{\frac{2\gamma}{\gamma-1}} \quad [\text{isen, perf}] \quad (35)$$

#### BERNOULLI'S EQUATION

Combination of equations (32b) and (35) gives Bernoulli's equation for compressible flow in the form

$$\frac{\gamma}{\gamma-1} \left(\frac{p}{\rho}\right) \left(\frac{p}{p_i}\right)^{\frac{\gamma}{\gamma-1}} + \frac{V^2}{2} = \frac{\gamma}{\gamma-1} \left(\frac{p_i}{\rho_i}\right) \quad [\text{isen, perf}] \quad (36)$$

#### RELATIONS BETWEEN LOCAL AND FREE-STREAM CONDITIONS

With the aid of the foregoing equations it can be shown that

$$\frac{T}{T_\infty} = 1 - \frac{\gamma-1}{2} M_\infty^2 \left[ \left( \frac{V}{V_\infty} \right)^2 - 1 \right] \quad [\text{adiab, perf}] \quad (37)$$

$$\frac{p}{p_\infty} = \left\{ 1 - \frac{\gamma-1}{2} M_\infty^2 \left[ \left( \frac{V}{V_\infty} \right)^2 - 1 \right] \right\}^{\frac{1}{\gamma-1}} \quad [\text{isen, perf}] \quad (38)$$

$$\frac{\rho}{\rho_\infty} = \left\{ 1 - \frac{\gamma-1}{2} M_\infty^2 \left[ \left( \frac{V}{V_\infty} \right)^2 - 1 \right] \right\}^{\frac{1}{\gamma-1}} \quad [\text{isen perf}] \quad (39)$$

In small-disturbance theory, where it is assumed  $(V - V_\infty) \ll V_\infty$ , these equations take on the simplified form

$$\frac{T}{T_\infty} \approx 1 - (\gamma-1) M_\infty^2 \frac{V - V_\infty}{V_\infty} \quad [\text{adiab, perf}] \quad (40)$$

$$\frac{p}{p_\infty} \approx 1 - \gamma M_\infty^2 \frac{V - V_\infty}{V_\infty} \quad [\text{isen, perf}] \quad (41)$$

$$\frac{\rho}{\rho_\infty} \approx 1 - M_\infty^2 \frac{V - V_\infty}{V_\infty} \quad [\text{isen, perf}] \quad (42)$$

#### USEFUL RATIOS

On the basis of the above results, useful relations can be derived expressing various dimensionless ratios as functions of a single parameter. These relations are given below grouped according to which of the various parameters ( $M$ ,  $V/a_*$ ,  $V/a_i$ , or  $V/V_\infty$ ) is used as the independent variable.

In each case the second form of the equation applies for  $\gamma = \frac{7}{5}$

Parameter  $M$ —

$$\frac{T}{T_i} = \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-1} = \left( 1 + \frac{M^2}{5} \right)^{-1} \quad [\text{adiab, perf}] \quad (43)$$

$$\frac{p}{p_i} = \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{\gamma}{\gamma-1}} = \left( 1 + \frac{M^2}{5} \right)^{-\frac{5}{2}} \quad [\text{isen, perf}] \quad (44)$$

$$\frac{\rho}{\rho_i} = \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{1}{\gamma-1}} = \left( 1 + \frac{M^2}{5} \right)^{-\frac{5}{2}} \quad [\text{isen, perf}] \quad (45)$$

$$\frac{a}{a_i} = \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{1}{2}} = \left( 1 + \frac{M^2}{5} \right)^{-\frac{1}{2}} \quad [\text{adiab, perf}] \quad (46)$$

$$\frac{q}{p} = \frac{\gamma}{2} M^2 = \frac{7}{10} M^2 \quad [\text{therm perf}] \quad (47)$$

$$\begin{aligned} \frac{q}{p_t} &= \frac{\gamma}{2} M^2 \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{1}{\gamma-1}} \\ &= \frac{7}{10} M^2 \left( 1 + \frac{M^2}{5} \right)^{-\frac{1}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (48)$$

$$\begin{aligned} \left( \frac{V}{a_t} \right)^2 &= M^2 \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-1} \\ &= M^2 \left( 1 + \frac{M^2}{5} \right)^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (49)$$

$$\begin{aligned} \left( \frac{V}{a_*} \right)^2 &= \frac{\gamma+1}{2} M^2 \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-1} \\ &= \frac{6M^2}{5} \left( 1 + \frac{M^2}{5} \right)^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (50)$$

$$\begin{aligned} \left( \frac{V}{V_m} \right)^2 &= \frac{\gamma-1}{2} M^2 \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{-1} \\ &= \frac{M^2}{5} \left( 1 + \frac{M^2}{5} \right)^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (51)$$

Parameter  $\frac{V}{a_*}$ .

$$\frac{T}{T_t} = 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 = 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \quad [\text{adiab, perf}] \quad (52)$$

$$\begin{aligned} \frac{p}{p_t} &= \left[ 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \left[ 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{1}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (53)$$

$$\begin{aligned} \frac{\rho}{\rho_t} &= \left[ 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \left[ 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (54)$$

$$\begin{aligned} \frac{a}{a_t} &= \left[ 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{1}{2}} \\ &= \left[ 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{1}{2}} \quad [\text{adiab, perf}] \end{aligned} \quad (55)$$

$$\begin{aligned} \frac{q}{p} &= \frac{\gamma}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \left[ 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \right]^{-1} \\ &= \frac{7}{12} \left( \frac{V}{a_*} \right)^2 \left[ 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \right]^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (56)$$

$$\begin{aligned} \frac{q}{p_t} &= \frac{\gamma}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \left[ 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \frac{7}{12} \left( \frac{V}{a_*} \right)^2 \left[ 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (57)$$

$$M^2 = \frac{2}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \left[ 1 - \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 \right]^{-1}$$

$$= \frac{5}{6} \left( \frac{V}{a_*} \right)^2 \left[ 1 - \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \right]^{-1} \quad [\text{adiab, perf}] \quad (58)$$

$$\left( \frac{V}{a_t} \right)^2 = \frac{2}{\gamma+1} \left( \frac{V}{a_*} \right)^2 = \frac{5}{6} \left( \frac{V}{a_*} \right)^2 \quad [\text{adiab, perf}] \quad (59)$$

$$\left( \frac{V}{V_m} \right)^2 = \frac{\gamma-1}{\gamma+1} \left( \frac{V}{a_*} \right)^2 = \frac{1}{6} \left( \frac{V}{a_*} \right)^2 \quad [\text{adiab, perf}] \quad (60)$$

Parameter  $\frac{V}{a_t}$ .

$$\frac{T}{T_t} = 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 = 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \quad [\text{adiab, perf}] \quad (61)$$

$$\begin{aligned} \frac{p}{p_t} &= \left[ 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \left[ 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{1}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (62)$$

$$\begin{aligned} \frac{\rho}{\rho_t} &= \left[ 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \left[ 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (63)$$

$$\begin{aligned} \frac{a}{a_t} &= \left[ 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{1}{2}} \\ &= \left[ 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{1}{2}} \quad [\text{adiab, perf}] \end{aligned} \quad (64)$$

$$\begin{aligned} \frac{q}{p} &= \frac{\gamma}{2} \left( \frac{V}{a_t} \right)^2 \left[ 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 \right]^{-1} \\ &= \frac{7}{10} \left( \frac{V}{a_t} \right)^2 \left[ 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \right]^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (65)$$

$$\begin{aligned} \frac{q}{p_t} &= \frac{\gamma}{2} \left( \frac{V}{a_t} \right)^2 \left[ 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \frac{7}{10} \left( \frac{V}{a_t} \right)^2 \left[ 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \end{aligned} \quad (66)$$

$$\begin{aligned} M^2 &= \left( \frac{V}{a_t} \right)^2 \left[ 1 - \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 \right]^{-1} \\ &= \left( \frac{V}{a_t} \right)^2 \left[ 1 - \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \right]^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (67)$$

$$\left( \frac{V}{a_*} \right)^2 = \frac{\gamma+1}{2} \left( \frac{V}{a_t} \right)^2 = \frac{6}{5} \left( \frac{V}{a_t} \right)^2 \quad [\text{adiab, perf}] \quad (68)$$

$$\left( \frac{V}{V_m} \right)^2 = \frac{\gamma-1}{2} \left( \frac{V}{a_t} \right)^2 = \frac{1}{5} \left( \frac{V}{a_t} \right)^2 \quad [\text{adiab, perf}] \quad (69)$$

Parameter  $\frac{V}{V_m}$ .

$$\frac{T}{T_i} = 1 - \left(\frac{V}{V_m}\right)^2 \quad [\text{adiab, perf}] \quad (70)$$

$$\frac{p}{p_i} = \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{\gamma}{\gamma-1}} = \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen. perf}] \quad (71)$$

$$\frac{\rho}{\rho_i} = \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{1}{\gamma-1}} = \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen. perf}] \quad (72)$$

$$\frac{a}{a_i} = \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{1}{2}} \quad [\text{adiab, perf}] \quad (73)$$

$$\begin{aligned} \frac{q}{p_i} &= \frac{\gamma}{\gamma-1} \left(\frac{V}{V_m}\right)^2 \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{-1} \\ &= \frac{7}{2} \left(\frac{V}{V_m}\right)^2 \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (74)$$

$$\begin{aligned} \frac{q}{p_i} &= \frac{\gamma}{\gamma-1} \left(\frac{V}{V_m}\right)^2 \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{1}{\gamma-1}} \\ &= \frac{7}{2} \left(\frac{V}{V_m}\right)^2 \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen. perf}] \end{aligned} \quad (75)$$

$$\begin{aligned} M^2 &= \frac{2}{\gamma+1} \left(\frac{V}{V_m}\right)^2 \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{-1} \\ &= \frac{5}{6} \left(\frac{V}{V_m}\right)^2 \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{-1} \quad [\text{adiab, perf}] \end{aligned} \quad (76)$$

$$\left(\frac{V}{a_i}\right)^2 = \frac{2}{\gamma-1} \left(\frac{V}{V_m}\right)^2 = 5 \left(\frac{V}{V_m}\right)^2 \quad [\text{adiab, perf}] \quad (77)$$

$$\left(\frac{V}{a_*}\right)^2 = \frac{\gamma+1}{\gamma-1} \left(\frac{V}{V_m}\right)^2 = 6 \left(\frac{V}{V_m}\right)^2 \quad [\text{adiab, perf}] \quad (78)$$

Tables I and II list numerical values of the following ratios with Mach number  $M$  as the independent variable:

$$\frac{p}{p_i}, \frac{\rho}{\rho_i}, \frac{T}{T_i}, \frac{q}{p_i}, \frac{V}{a_*}$$

#### STREAM-TUBE-AREA RELATIONS

If it is assumed that the density and speed are uniform across any section of a given stream tube, then the equation of continuity is

$$\rho V A = \text{constant} = \rho_* a_* A_* \quad (79)$$

By combining this and certain of the foregoing equations, the area ratio  $A_*/A$  can be expressed as a function of any one of the four parameters used above. The final equations are

$$\begin{aligned} \frac{A_*}{A} &= \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} M \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}} \\ &= \frac{216}{125} M \left(1 + \frac{M^2}{5}\right)^{-3} \quad [\text{isen. perf}] \end{aligned} \quad (80)$$

$$\frac{A_*}{A} = \left(\frac{\gamma+1}{2}\right)^{\frac{1}{\gamma-1}} \left(\frac{V}{a_*}\right) \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{\frac{1}{\gamma-1}}$$

$$= \left(\frac{6}{5}\right)^{\frac{5}{2}} \left(\frac{V}{a_*}\right) \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen. perf}]$$

$$\frac{A_*}{A} = \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{V}{a_i}\right) \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{\frac{1}{\gamma-1}}$$

$$= \frac{216}{125} \left(\frac{V}{a_i}\right) \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen. perf}] \quad (82)$$

$$\frac{A_*}{A} = \left(\frac{2}{\gamma-1}\right)^{\frac{1}{2}} \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{V}{V_m}\right) \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{1}{\gamma-1}}$$

$$= 5^{\frac{1}{2}} \left(\frac{216}{125}\right) \left(\frac{V}{V_m}\right) \left[1 - \left(\frac{V}{V_m}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen. perf}] \quad (83)$$

Numerical values of  $A_*/A$  as a function of  $M$  are given in tables I and II.

Equation (79) combined with equations (26), (29b), (45) and (46) can be employed to obtain the mass-flow rate per unit area  $\rho V$  along a stream tube as a function of Mach number, total temperature, and total pressure. Numerical values can be obtained conveniently from chart 1 where the variation with Mach number of the mass-flow rate per unit cross-sectional area is presented for various total temperatures and a total pressure of 1 pound per square inch absolute.

## SHOCK WAVES

### NORMAL SHOCK WAVES

#### BASIC EQUATIONS

The previous relations for isentropic flow are valid on either side of a shock wave, but not across it, because at the shock wave the flow quantities have discontinuities. Jumping

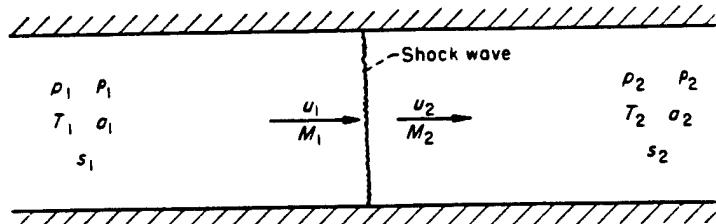


FIGURE 1.—Notation for normal shock wave.

conditions for a steady normal shock wave (fig. 1) result from requiring conservation of

$$\text{mass:} \quad \rho_1 u_1 = \rho_2 u_2 \quad (84)$$

$$\text{momentum:} \quad p_1 + \rho_1 u_1^2 = p_2 + \rho_2 u_2^2 \quad (85)$$

$$\text{energy:}^3 \quad \frac{1}{2} u_1^2 + h_1 = \frac{1}{2} u_2^2 + h_2 \quad [\text{adiab}]$$

<sup>3</sup> The actual relation for conservation of energy is  $\rho_1 u_1 \left(\frac{1}{2} u_1^2 + h_1\right) = \rho_2 u_2 \left(\frac{1}{2} u_2^2 + h_2\right)$ ; it reduces to the above form in view of equation (84).

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

$$\left. \begin{aligned} \frac{1}{2} u_1^2 + c_p T_1 &= \frac{1}{2} u_2^2 + c_p T_2 \\ \frac{1}{2} u_1^2 + \frac{\gamma}{\gamma-1} \frac{p_1}{\rho_1} &= \frac{1}{2} u_2^2 + \frac{\gamma}{\gamma-1} \frac{p_2}{\rho_2} \\ \frac{1}{2} u_1^2 + \frac{1}{\gamma-1} a_1^2 &= \frac{1}{2} u_2^2 + \frac{1}{\gamma-1} a_2^2 \end{aligned} \right\} \text{[adiab, perf]} \quad (86b)$$

together with the requirement that the entropy does not decrease:

$$\Delta s \equiv s_2 - s_1 \geq 0 \quad (87)$$

It follows immediately from the energy relation (86) that total enthalpy, total temperature, and total speed of sound are constant across the shock and hence (from the previous relations (33) for adiabatic flow) also the critical speed of sound and limiting speed:

$$h_{t_1} = h_{t_2} \quad \text{[adiab]} \quad (88a)$$

$$\left. \begin{aligned} T_{t_1} &= T_{t_2} \\ a_{t_1} &= a_{t_2} \\ a_{*1} &= a_{*2} \\ V_{m_1} &= V_{m_2} \end{aligned} \right\} \text{[adiab, perf]} \quad (88b)$$

Combining equations (84) to (86) leads to Prandtl's relation

$$u_1 u_2 = a_*^2 = \frac{p_2 - p_1}{\rho_2 - \rho_1} \quad \text{[adiab, perf]} \quad (89)$$

which implies that the flow is supersonic ahead of the shock wave and subsonic behind (the reverse possibility is ruled out by the requirement of nondecreasing entropy), and to the Rankine-Hugoniot relations

$$\frac{p_2}{p_1} = \frac{(\gamma+1)\rho_2 - (\gamma-1)\rho_1}{(\gamma+1)\rho_1 - (\gamma-1)\rho_2} \quad \text{[adiab, perf]} \quad (90)$$

$$\frac{p_2}{p_1} = \frac{(\gamma+1)p_2 + (\gamma-1)p_1}{(\gamma+1)p_1 + (\gamma-1)p_2} \quad \text{[adiab, perf]} \quad (91)$$

$$\frac{p_2 - p_1}{\rho_2 - \rho_1} = \gamma \frac{p_2 + p_1}{\rho_2 + \rho_1} \quad \text{[adiab, perf]} \quad (92)$$

## USEFUL RELATIONS

Many relations for normal shock waves are conveniently expressed in terms of either upstream Mach number  $M_1$  or the static-pressure ratio across the shock  $\xi \equiv p_2/p_1$ . The following relations apply to adiabatic flow of a completely perfect fluid. The last form of each equation holds for  $\gamma = 7/5$ .

Parameter  $M_1$ .—

$$\frac{p_2}{p_1} \equiv \xi = \frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1} = \frac{7M_1^2 - 1}{6} \quad (93)$$

$$\frac{p_2}{p_1} = \frac{u_1}{u_2} = \frac{u_1^2}{a_*^2} = \frac{a_*^2}{u_2^2} = \frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2 + 2} = \frac{6M_1^2}{M_1^2 + 5} \quad (94)$$

$$\frac{T_2}{T_1} = \frac{a_2^2}{a_1^2} = \frac{[2\gamma M_1^2 - (\gamma-1)][(\gamma-1)M_1^2 + 2]}{(\gamma+1)^2 M_1^2} = \frac{(7M_1^2 - 1)(M_1^2 + 5)}{36M_1^2} \quad (95)$$

$$M_2^2 = \frac{(\gamma-1)M_1^2 + 2}{2\gamma M_1^2 - (\gamma-1)} = \frac{M_1^2 + 5}{7M_1^2 - 1} \quad (96)$$

$$\frac{p_2}{p_{t_1}} = \frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1} \left[ \frac{2}{(\gamma-1)M_1^2 + 2} \right]^{\frac{1}{\gamma-1}} = \frac{7M_1^2 - 1}{6} \left( \frac{5}{M_1^2 + 5} \right)^{\frac{1}{2}} \quad (97)$$

$$\frac{p_2}{p_{t_2}} = \left[ \frac{4\gamma M_1^2 - 2(\gamma-1)}{(\gamma+1)^2 M_1^2} \right]^{\frac{1}{\gamma-1}} = \left[ \frac{5(7M_1^2 - 1)}{36M_1^2} \right]^{\frac{1}{2}} \quad (98)$$

$$\frac{p_{t_2}}{p_{t_1}} = \frac{p_{t_2}}{p_{t_1}} e^{-\frac{\Delta s}{R}} = \left[ \frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2 + 2} \right]^{\frac{1}{\gamma-1}} \left[ \frac{\gamma+1}{2\gamma M_1^2 - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} = \left( \frac{6M_1^2}{M_1^2 + 5} \right)^{\frac{1}{2}} \left( \frac{6}{7M_1^2 - 1} \right)^{\frac{1}{2}} \quad (99)$$

$$\frac{p_{t_2}}{p_1} = \left[ \frac{(\gamma+1)M_1^2}{2} \right]^{\frac{1}{\gamma-1}} \left[ \frac{\gamma+1}{2\gamma M_1^2 - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} = \left( \frac{6M_1^2}{5} \right)^{\frac{1}{2}} \left( \frac{6}{7M_1^2 - 1} \right)^{\frac{1}{2}} \quad (100)$$

(Rayleigh pitot formula)

$$\begin{aligned} \frac{\Delta s}{c_v} &= (\gamma-1) \frac{\Delta s}{R} = -(\gamma-1) \ln \left( \frac{p_{t_2}}{p_{t_1}} \right) \\ &= \ln \left[ \frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1} \right] - \gamma \ln \left[ \frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2 + 2} \right] \\ &= \ln \left( \frac{7M_1^2 - 1}{6} \right) - \frac{7}{5} \ln \left( \frac{6M_1^2}{M_1^2 + 5} \right) \end{aligned} \quad (101)$$

$$\frac{p_2 - p_1}{q_1} = \frac{4(M_1^2 - 1)}{(\gamma+1)M_1^2} = \frac{5(M_1^2 - 1)}{3M_1^2} \quad (102)$$

Numerical values from equations (93), (94), (95), (96), (99), and (100) (with  $\gamma = 7/5$ ) are given in table II.

For weak shock waves ( $M_1$  only slightly greater than unity) the following series are useful:

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= 1 - \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 - 1)^3 + \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 - 1)^4 + \dots \\ &= 1 - \frac{35}{216} (M_1^2 - 1)^3 + \frac{245}{864} (M_1^2 - 1)^4 + \dots \end{aligned} \quad (103)$$

$$\begin{aligned} \frac{\Delta s}{R} &= \frac{1}{\gamma-1} \frac{\Delta s}{c_v} = \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 - 1)^3 - \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 - 1)^4 + \dots \\ &= \frac{35}{216} (M_1^2 - 1)^3 - \frac{245}{864} (M_1^2 - 1)^4 + \dots \end{aligned} \quad (104)$$

Parameter  $\xi \equiv p_2/p_1$ .

$$M_1^2 = \frac{(\gamma+1)\xi + (\gamma-1)}{2\gamma} = \frac{6\xi+1}{7} \quad (105)$$

$$\frac{p_2}{p_1} = \frac{u_1}{u_2} = \frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} = \frac{6\xi+1}{\xi+6} \quad (106)$$

$$\frac{T_2}{T_1} = \frac{a_1^2}{a_2^2} = \xi \frac{(\gamma-1)\xi + (\gamma+1)}{(\gamma+1)\xi + (\gamma-1)} = \xi \frac{\xi+6}{6\xi+1} \quad (107)$$

$$M_2^2 = \frac{(\gamma-1)\xi + (\gamma+1)}{2\gamma\xi} = \frac{\xi+6}{7\xi} \quad (108)$$

$$\frac{p_2}{p_{t_1}} = \xi \frac{p_1}{p_{t_1}} = \xi \left\{ \frac{4\gamma}{(\gamma+1)[(\gamma-1)\xi + (\gamma+1)]} \right\}^{\frac{1}{\gamma-1}} = \xi \left[ \frac{35}{6(\xi+6)} \right]^{\frac{1}{2}} \quad (109)$$

$$\frac{p_2}{p_{t_2}} = \xi \frac{p_1}{p_{t_2}} = \left\{ \frac{4\gamma\xi}{(\gamma+1)[(\gamma+1)\xi + (\gamma-1)]} \right\}^{\frac{1}{\gamma-1}} = \left[ \frac{35\xi}{6(6\xi+1)} \right]^{\frac{1}{2}} \quad (110)$$

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= e^{-\frac{\Delta s}{R}} = \xi^{-\frac{1}{\gamma-1}} \left[ \frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} \right]^{\frac{1}{\gamma-1}} \\ &= \left( \frac{1}{\xi} \right)^{\frac{5}{2}} \left( \frac{6\xi+1}{\xi+6} \right)^{\frac{1}{2}} \end{aligned} \quad (111)$$

$$\begin{aligned} \frac{\Delta s}{c_s} &= (\gamma-1) \frac{\Delta s}{R} = -(\gamma-1) \ln \left( \frac{p_{t_2}}{p_{t_1}} \right) = \ln \xi - \\ &\quad \gamma \ln \left[ \frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} \right] = \ln \xi - \frac{7}{5} \ln \left( \frac{6\xi+1}{\xi+6} \right) \end{aligned} \quad (112)$$

For weak shock waves ( $\xi$  only slightly greater than unity)

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= 1 - \frac{\gamma+1}{12\gamma^2} (\xi-1)^3 + \frac{\gamma+1}{8\gamma^2} (\xi-1)^4 + \dots \\ &= 1 - \frac{5}{49} (\xi-1)^3 + \frac{15}{98} (\xi-1)^4 + \dots \end{aligned} \quad (113)$$

$$\begin{aligned} \frac{\Delta s}{R} &= \frac{1}{\gamma-1} \frac{\Delta s}{c_s} = \frac{\gamma+1}{12\gamma^2} (\xi-1)^3 - \frac{\gamma+1}{8\gamma^2} (\xi-1)^4 + \dots \\ &= \frac{5}{49} (\xi-1)^3 - \frac{15}{98} (\xi-1)^4 + \dots \end{aligned} \quad (114)$$

In unsteady flow a normal shock wave acts at each instant as a steady shock. Hence all the above relations are valid across a moving normal shock wave if instantaneous velocities are measured relative to the shock.

### OBLIQUE SHOCK WAVES

In general, a three-dimensional shock wave will be curved, and will separate two regions of nonuniform flow. However, the shock transition at each point takes place instantaneously, so that it is sufficient to consider an arbitrarily small neighborhood of the point. In such a neighborhood

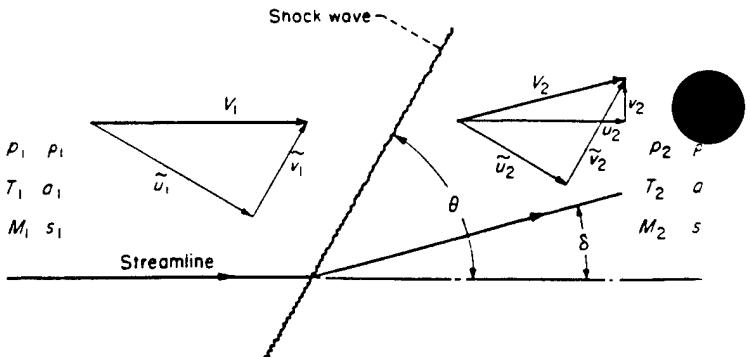


FIGURE 2.—Notation for oblique shock wave.

the shock wave may be regarded as plane to any desired degree of accuracy, and the flows on either side as uniform and parallel. Moreover, with the proper orientation of axes the flow is locally two-dimensional. Hence it is sufficient to consider a straight oblique shock wave in a uniform parallel two-dimensional stream, as shown in figure 2.

### BASIC EQUATIONS

For a steady oblique shock wave, jump conditions result from requiring conservation of

$$\text{mass: } \rho_1 \bar{u}_1 = \rho_2 \bar{u}_2 \quad (115)$$

$$\text{normal momentum: } p_1 + \rho_1 \bar{u}_1^2 = p_2 + \rho_2 \bar{u}_2^2 \quad (116)$$

$$\text{tangential momentum: } \rho_1 \bar{u}_1 \bar{v}_1 = \rho_2 \bar{u}_2 \bar{v}_2 \quad (117)$$

$$\text{energy: } \frac{1}{2} (\bar{u}_1^2 + \bar{v}_1^2) + h_1 = \frac{1}{2} (\bar{u}_2^2 + \bar{v}_2^2) + h_2 \text{ [adiab]} \quad (118)$$

$$\begin{aligned} \frac{1}{2} (\bar{u}_1^2 + \bar{v}_1^2) + c_p T_1 &= \frac{1}{2} (\bar{u}_2^2 + \bar{v}_2^2) + c_p T_2 \\ \frac{1}{2} (\bar{u}_1^2 + \bar{v}_1^2) + \frac{\gamma}{\gamma-1} \frac{p_1}{\rho_1} &= \frac{1}{2} (\bar{u}_2^2 + \bar{v}_2^2) + \frac{\gamma}{\gamma-1} \frac{p_2}{\rho_2} \quad \left. \right\} \text{ [adiab, perf]} \\ \frac{1}{2} (\bar{u}_1^2 + \bar{v}_1^2) + \frac{1}{\gamma-1} a_1^2 &= \frac{1}{2} (\bar{u}_2^2 + \bar{v}_2^2) + \frac{1}{\gamma-1} a_2^2 \end{aligned} \quad (118b)$$

together with the requirement that the entropy does not decrease:

$$\Delta s \equiv s_2 - s_1 \geq 0 \quad (119)$$

Again it follows from the energy relation (118) that total enthalpy, total temperature, and total speed of sound are constant across the shock and hence also the critical speed of sound and limiting speed:

$$h_{t_1} = h_{t_2} \quad \text{[adiab]} \quad (120)$$

$$\left. \begin{aligned} T_{t_1} &= T_{t_2} \\ a_{t_1} &= a_{t_2} \\ a_{*1} &= a_{*2} \\ V_{m_1} &= V_{m_2} \end{aligned} \right\} \quad \left. \begin{aligned} & \text{[adiab, perf]} \\ & \text{[perf]} \end{aligned} \right\}$$

\* Compare remark for normal shock waves, footnote on page 6.

## CONNECTION WITH NORMAL SHOCK

comparison of equation (115) with (117) shows that tangential velocity is constant across the shock wave:

$$\tilde{v}_1 = \tilde{v}_2 \quad [\text{adiab}] \quad (122)$$

so that the change in velocity is normal to the shock. It follows that

$$\frac{1}{2} \tilde{v}_1^2 = \frac{1}{2} \tilde{v}_2^2$$

so that the energy equation (118a) reduces to

$$\frac{1}{2} \tilde{u}_1^2 + h_1 = \frac{1}{2} \tilde{u}_2^2 + h_2 \quad [\text{adiab}] \quad (123)$$

Now equations (115), (116), and (123) involve only the component of velocity  $\tilde{u}$  normal to the shock, and are identical with equations (84), (85), and (86) for normal shock waves. Hence an oblique shock wave acts as a normal shock to the component of flow perpendicular to it, while the tangential component is unchanged. This is also clear physically from the "sweepback principle" that the oblique flow is reduced to the normal flow by a uniform translation of axes (Galilean transformation).

Because the speed of sound depends on the tangential velocity, Prandtl's relation differs from that for normal shock waves (see ref. 11, pp. 302-303):

$$\tilde{u}_1 \tilde{u}_2 = a_*^2 - \frac{\gamma-1}{\gamma+1} \tilde{v}^2 \quad [\text{adiab, perf}] \quad (124)$$

where  $a_*$  and  $\tilde{v}$  can be evaluated on either side of the shock.

The Rankine-Hugoniot relations are the same as for normal shock waves:

$$\frac{p_2}{p_1} = \frac{(\gamma+1)\rho_2 - (\gamma-1)\rho_1}{(\gamma+1)\rho_1 - (\gamma-1)\rho_2} \quad [\text{adiab, perf}] \quad (125)$$

$$\frac{p_2}{p_1} = \frac{(\gamma+1)p_2 + (\gamma-1)p_1}{(\gamma+1)p_1 + (\gamma-1)p_2} \quad [\text{adiab, perf}] \quad (126)$$

$$\frac{p_2 - p_1}{\rho_2 - \rho_1} = \gamma \frac{p_2 + p_1}{\rho_2 + \rho_1} \quad [\text{adiab, perf}] \quad (127)$$

## USEFUL RELATIONS

Because an oblique shock wave acts as a normal shock to the flow perpendicular to it, the previous relations for normal shocks (except those for ratios of static to total pressures) apply to oblique shocks if  $M_1$  and  $M_2$  are replaced by their normal components  $M_1 \sin \theta$  and  $M_2 \sin(\theta-\delta)$ . This gives most of the following relations; the remainder are derived from them by using the kinematic condition that the stream turns through an angle  $\delta$ , together with the various isentropic-flow relations.

meters  $M_1$  and  $\theta$ .

$$\frac{p_2}{p_1} = \xi = \frac{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)}{\gamma+1} = \frac{7M_1^2 \sin^2 \theta - 1}{6} \quad (128)$$

$$\frac{\rho_2}{\rho_1} = \frac{\tilde{u}_1}{\tilde{u}_2} = \frac{(\gamma+1)M_1^2 \sin^2 \theta}{(\gamma-1)M_1^2 \sin^2 \theta + 2} = \frac{6M_1^2 \sin^2 \theta}{M_1^2 \sin^2 \theta + 5} \quad (129)$$

$$\begin{aligned} \frac{T_2}{T_1} &= \frac{a_2^2}{a_1^2} = \frac{[2\gamma M_1^2 \sin^2 \theta - (\gamma-1)][(\gamma-1)M_1^2 \sin^2 \theta + 2]}{(\gamma+1)^2 M_1^2 \sin^2 \theta} \\ &= \frac{(7M_1^2 \sin^2 \theta - 1)(M_1^2 \sin^2 \theta + 5)}{36M_1^2 \sin^2 \theta} \end{aligned} \quad (130)$$

$$M_2^2 \sin^2(\theta - \delta) = \frac{(\gamma-1)M_1^2 \sin^2 \theta + 2}{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)} = \frac{M_1^2 \sin^2 \theta + 5}{7M_1^2 \sin^2 \theta - 1} \quad (131)$$

$$\begin{aligned} M_2^2 &= \frac{(\gamma+1)^2 M_1^4 \sin^2 \theta - 4(M_1^2 \sin^2 \theta - 1)(\gamma M_1^2 \sin^2 \theta + 1)}{[2\gamma M_1^2 \sin^2 \theta - (\gamma-1)][(\gamma-1)M_1^2 \sin^2 \theta + 2]} \\ &= \frac{36M_1^4 \sin^2 \theta - 5(M_1^2 \sin^2 \theta - 1)(7M_1^2 \sin^2 \theta + 5)}{(7M_1^2 \sin^2 \theta - 1)(M_1^2 \sin^2 \theta + 5)} \end{aligned} \quad (132)$$

$$\frac{\tilde{u}_2}{V_1} = \frac{(\gamma-1)M_1^2 \sin^2 \theta + 2}{(\gamma+1)M_1^2 \sin^2 \theta} \sin \theta = \frac{M_1^2 \sin^2 \theta + 5}{6M_1^2 \sin^2 \theta} \sin \theta \quad (133)$$

$$\frac{\tilde{v}_2}{V_1} = \frac{\tilde{v}_1}{V_1} = \cos \theta \quad (134)$$

$$\frac{u_2}{V_1} = 1 - \frac{2(M_1^2 \sin^2 \theta - 1)}{(\gamma+1)M_1^2} = 1 - \frac{5(M_1^2 \sin^2 \theta - 1)}{6M_1^2} \quad (135)$$

$$\frac{v_2}{V_1} = \frac{2(M_1^2 \sin^2 \theta - 1)}{(\gamma+1)M_1^2} \cot \theta = \frac{5(M_1^2 \sin^2 \theta - 1)}{6M_1^2} \cot \theta \quad (136)$$

$$\begin{aligned} \frac{V_2^2}{V_1^2} &= 1 - 4 \frac{(M_1^2 \sin^2 \theta - 1)(\gamma M_1^2 \sin^2 \theta + 1)}{(\gamma+1)^2 M_1^4 \sin^2 \theta} \\ &= 1 - \frac{5}{36} \frac{(M_1^2 \sin^2 \theta - 1)(7M_1^2 \sin^2 \theta + 5)}{M_1^4 \sin^2 \theta} \end{aligned} \quad (137)$$

$$\begin{aligned} \cot \delta &= \tan \theta \left[ \frac{(\gamma+1)M_1^2}{2(M_1^2 \sin^2 \theta - 1)} - 1 \right] \\ &= \tan \theta \left[ \frac{6M_1^2}{5(M_1^2 \sin^2 \theta - 1)} - 1 \right] \end{aligned} \quad (138)$$

$$\tan \delta = \frac{2 \cot \theta (M_1^2 \sin^2 \theta - 1)}{2 + M_1^2 (\gamma + 1 - 2 \sin^2 \theta)} = \frac{5 \cot \theta (M_1^2 \sin^2 \theta - 1)}{5 + M_1^2 (6 - 5 \sin^2 \theta)} \quad (139a)$$

$$= \frac{M_1^2 \sin 2\theta - 2 \cot \theta}{2 + M_1^2 (\gamma + \cos 2\theta)} = 5 \frac{M_1^2 \sin 2\theta - 2 \cot \theta}{10 + M_1^2 (7 + 5 \cos 2\theta)} \quad (139b)$$

$$\begin{aligned} \frac{p_2}{p_{t_1}} &= \frac{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)}{(\gamma+1)} \left[ \frac{2}{(\gamma-1)M_1^2 + 2} \right]^{\frac{\gamma}{\gamma-1}} \\ &= \frac{7M_1^2 \sin^2 \theta - 1}{6} \left( \frac{5}{M_1^2 + 5} \right)^{7/2} \end{aligned} \quad (140)$$

$$\begin{aligned} \frac{p_2}{p_{t_2}} &= \left\{ 2 \frac{[2\gamma M_1^2 \sin^2 \theta - (\gamma-1)][(\gamma-1)M_1^2 \sin^2 \theta + 2]}{(\gamma+1)^2 M_1^2 \sin^2 \theta} \right\}^{\frac{\gamma}{\gamma-1}} \\ &= \left[ 5 \frac{(7M_1^2 \sin^2 \theta - 1)(M_1^2 \sin^2 \theta + 5)}{36M_1^2 \sin^2 \theta (M_1^2 + 5)} \right]^{7/2} \end{aligned} \quad (141)$$

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= \frac{\rho_{t_2}}{\rho_{t_1}} = e^{-\frac{\Delta s}{R}} \\ &= \left[ \frac{(\gamma+1)M_1^2 \sin^2 \theta}{(\gamma-1)M_1^2 \sin^2 \theta + 2} \right]^{\frac{1}{\gamma-1}} \left[ \frac{\gamma+1}{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} \\ &= \left( \frac{6M_1^2 \sin^2 \theta}{M_1^2 \sin^2 \theta + 5} \right)^{1/2} \left( \frac{6}{7M_1^2 \sin^2 \theta - 1} \right)^{5/2} \end{aligned} \quad (142)$$

$$\begin{aligned} \frac{p_{t_2}}{p_1} &= \left[ \frac{\gamma+1}{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} \times \\ &\quad \left\{ \frac{(\gamma+1)M_1^2 \sin^2 \theta [(\gamma-1)M_1^2 + 2]}{2[(\gamma-1)M_1^2 \sin^2 \theta + 2]} \right\}^{\frac{1}{\gamma-1}} \\ &= \left( \frac{6}{7M_1^2 \sin^2 \theta - 1} \right)^{5/2} \left[ \frac{6M_1^2 \sin^2 \theta (M_1^2 + 5)}{5(M_1^2 \sin^2 \theta + 5)} \right]^{1/2} \end{aligned} \quad (143)$$

$$\begin{aligned} \frac{\Delta s}{c_r} &= (\gamma-1) \frac{\Delta s}{R} = -(\gamma-1) \ln \left( \frac{p_{t_2}}{p_{t_1}} \right) \\ &= \ln \left[ \frac{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)}{\gamma+1} \right] - \\ &\quad \gamma \ln \left[ \frac{(\gamma+1)M_1^2 \sin^2 \theta}{(\gamma-1)M_1^2 \sin^2 \theta + 2} \right] \\ &= \ln \left( \frac{7M_1^2 \sin^2 \theta - 1}{6} \right) - \frac{7}{5} \ln \left( \frac{6M_1^2 \sin^2 \theta}{M_1^2 \sin^2 \theta + 5} \right) \end{aligned} \quad (144)$$

$$\frac{p_2 - p_1}{q_1} = \frac{4(M_1^2 \sin^2 \theta - 1)}{(\gamma+1)M_1^2} = \frac{5}{3} \frac{M_1^2 \sin^2 \theta - 1}{M_1^2} \quad (145)$$

Values of the following ratios for oblique shock waves can be read from table II, provided  $M_1 \sin \theta$  is used instead of  $M_1$  in the first column:

$$\frac{p_2}{p_1}, \frac{\rho_2}{\rho_1}, \frac{T_2}{T_1}, \frac{p_{t_2}}{p_{t_1}}$$

For weak shock waves ( $M_1 \sin \theta$  only slightly greater than unity) the following series are obtained from equations (103) and (104) by replacing  $M_1$  by  $M_1 \sin \theta$ :

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= 1 - \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 \sin^2 \theta - 1)^3 + \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 \sin^2 \theta - 1)^4 + \dots \\ &= 1 - \frac{35}{216} (M_1^2 \sin^2 \theta - 1)^3 + \frac{245}{864} (M_1^2 \sin^2 \theta - 1)^4 + \dots \end{aligned} \quad (146)$$

$$\begin{aligned} \frac{\Delta s}{R} &= \frac{1}{\gamma-1} \frac{\Delta s}{c_r} = \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 \sin^2 \theta - 1)^3 - \\ &\quad \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 \sin^2 \theta - 1)^4 + \dots \\ &= \frac{35}{216} (M_1^2 \sin^2 \theta - 1)^3 - \frac{245}{864} (M_1^2 \sin^2 \theta - 1)^4 + \dots \end{aligned} \quad (147)$$

### Parameters $\theta$ and $\delta$ .

$$\begin{aligned} \frac{1}{M_1^2} &= \sin^2 \theta - \frac{\gamma+1}{2} \frac{\sin \theta \sin \delta}{\cos(\theta-\delta)} = \sin^2 \theta - \frac{\gamma+1}{2} \frac{\tan \delta}{\tan \delta + \cot \theta} \\ &= \sin^2 \theta - \frac{\gamma+1}{2} \frac{\tan \theta}{\tan \theta + \cot \delta} \end{aligned} \quad (148a)$$

$$\begin{aligned} M_1^2 &= \frac{2(\cot \theta + \tan \delta)}{\sin 2\theta - \tan \delta(\gamma + \cos 2\theta)} \\ &= \frac{10(\cot \theta + \tan \delta)}{5 \sin 2\theta - \tan \delta(7 + 5 \cos 2\theta)} \end{aligned} \quad (148b)$$

$$\begin{aligned} \frac{p_2 - p_1}{q_1} &= 2 \frac{\sin \theta \sin \delta}{\cos(\theta-\delta)} \\ &= 2 \frac{\tan \delta}{\tan \delta + \cot \theta} = 2 \frac{\tan \theta}{\tan \theta + \cot \delta} \end{aligned} \quad (149a)$$

$$\frac{p_2 - p_1}{p_2} = \frac{\sin \delta}{\sin \theta \cos(\theta-\delta)} \quad (149b)$$

### Parameters $M_1$ and $\delta$ .

No convenient explicit relations exist. However, the value of  $\sin^2 \theta$  can be found by solving the following cubic equation (ref. 12):

$$\sin^6 \theta + b \sin^4 \theta + c \sin^2 \theta + d = 0 \quad (150a)$$

where

$$\left. \begin{aligned} b &= -\frac{M_1^2 + 2}{M_1^2} - \gamma \sin^2 \delta \\ c &= \frac{2M_1^2 + 1}{M_1^4} + \left[ \frac{(\gamma+1)^2}{4} + \frac{\gamma-1}{M_1^2} \right] \sin^2 \delta \\ d &= -\frac{\cos^2 \delta}{M_1^4} \end{aligned} \right\} \quad (150b)$$

The smallest of the three roots corresponds to a decrease in entropy and should be disregarded.

For weak shock waves (small deflections  $\delta$ ) the following series are useful (note that  $\delta$  must be measured in radians):

$$\begin{aligned} \frac{p_2}{p_1} &= 1 + \frac{\gamma M_1^2}{(M_1^2 - 1)^{1/2}} \delta + \gamma M_1^2 \frac{(\gamma+1)M_1^4 - 4(M_1^2 - 1)}{4(M_1^2 - 1)^2} \delta^2 + \\ &\quad \frac{\gamma M_1^2}{(M_1^2 - 1)^{7/2}} \left[ \frac{(\gamma+1)^2}{32} M_1^8 - \frac{7 + 12\gamma - 3\gamma^2}{24} M_1^6 + \right. \\ &\quad \left. \frac{3}{4} (\gamma+1)M_1^4 - M_1^2 + \frac{2}{3} \right] \delta^3 + \dots \end{aligned} \quad (151)$$

$$\begin{aligned} \frac{p_2 - p_1}{q_1} &= \frac{2}{(M_1^2 - 1)^{1/2}} \delta + \frac{(\gamma+1)M_1^4 - 4(M_1^2 - 1)}{2(M_1^2 - 1)^2} \delta^2 + \\ &\quad \frac{1}{(M_1^2 - 1)^{7/2}} \left[ \frac{(\gamma+1)^2}{16} M_1^8 - \frac{7 + 12\gamma - 3\gamma^2}{12} M_1^6 + \right. \\ &\quad \left. \frac{3}{2} (\gamma+1)M_1^4 - 2M_1^2 + \frac{4}{3} \right] \delta^3 + \dots \end{aligned} \quad (152)$$

$$= 1 + \frac{M_1^2}{(M_1^2 - 1)^{1/2}} \delta + M_1^2 \frac{(3-\gamma)M_1^2(M_1^2 - 2) + 4}{4(M_1^2 - 1)^2} \delta^2 + \dots \quad (153)$$

$$\frac{T_2}{T_1} = 1 + \frac{(\gamma-1)M_1^2}{(M_1^2 - 1)^{1/2}} \delta + (\gamma-1)M_1^2 \frac{(\gamma+1)M_1^4 - 2(M_1^2 + 2)(M_1^2 - 1)}{4(M_1^2 - 1)^2} \delta^2 + \dots \quad (154)$$

Since flow through weak shock waves is nearly isentropic, compressions through small angles can also be calculated with the aid of table II by regarding them as reversed Prandtl-Meyer expansions (see later section). The resulting numerical accuracy is greater than that obtained by retaining terms up to  $\delta^2$  in the above series, and nearly equal to that obtained by retaining terms up to  $\delta^3$ .

Charts 2, 3, and 4 show the variation of shock-wave angle, pressure coefficient across a shock wave, and downstream Mach number with flow-deflection angle for various upstream Mach numbers.

Parameter  $\xi \equiv p_2/p_1$ .—

$$M_1^2 \sin^2 \theta = \frac{(\gamma+1)\xi + (\gamma-1)}{2\gamma} = \frac{6\xi + 1}{7} \quad (155)$$

$$M_2^2 \sin^2(\theta - \delta) = \frac{(\gamma-1)\xi + (\gamma+1)}{2\gamma\xi} = \frac{\xi + 6}{7\xi} \quad (156)$$

$$\begin{aligned} M_2^2 &= \frac{M_1^2[(\gamma+1)\xi + (\gamma-1)] - 2(\xi^2 - 1)}{\xi[(\gamma-1)\xi + (\gamma+1)]} \\ &= \frac{M_1^2(6\xi + 1) - 5(\xi^2 - 1)}{\xi(\xi + 6)} \end{aligned} \quad (157)$$

$$\frac{p_2}{p_1} = \frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} = \frac{6\xi + 1}{\xi + 6} \quad (158)$$

$$\frac{T_2}{T_1} = \frac{a_2^2}{a_1^2} = \xi \frac{(\gamma-1)\xi + (\gamma+1)}{(\gamma+1)\xi + (\gamma-1)} = \xi \frac{\xi + 6}{6\xi + 1} \quad (159)$$

$$\begin{aligned} \tan^2 \delta &= \left( \frac{\xi - 1}{\gamma M_1^2 - \xi + 1} \right)^2 \frac{2\gamma M_1^2 - (\gamma - 1) - (\gamma + 1)\xi}{(\gamma + 1)\xi + (\gamma - 1)} \\ &= \left[ \frac{5(\xi - 1)}{7M_1^2 - 5(\xi - 1)} \right]^2 \frac{7M_1^2 - (6\xi - 1)}{6\xi + 1} \end{aligned} \quad (160)$$

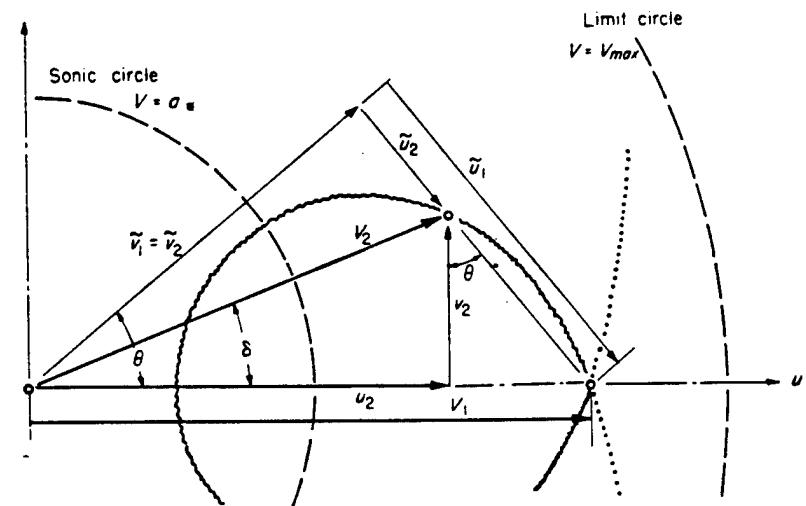
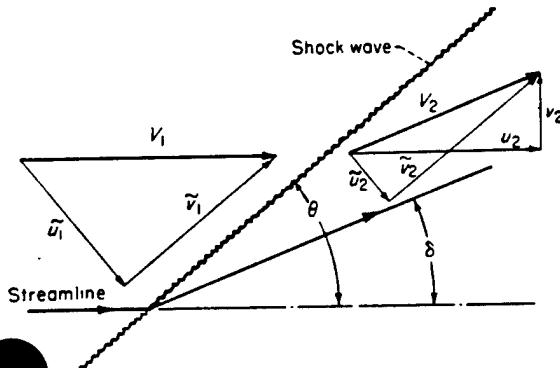


FIGURE 3.—Shock polar.

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= \frac{\rho_{t_2}}{\rho_{t_1}} = e^{-\frac{\Delta s}{R}} = \left[ \frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} \right]^{\frac{\gamma}{\gamma-1}} \xi^{-\frac{1}{\gamma-1}} \\ &= \left( \frac{6\xi + 1}{\xi + 6} \right)^{7/2} \xi^{-5/2} \end{aligned} \quad (161)$$

$$\frac{V_2^2}{V_1^2} = 1 - \frac{2(\xi^2 - 1)}{M_1^2[(\gamma+1)\xi + (\gamma-1)]} = 1 - \frac{5(\xi^2 - 1)}{M_1^2(6\xi + 1)} \quad (162)$$

For weak shock waves, equations (113) and (114) apply to oblique as well as normal shocks.

#### SHOCK POLAR

The velocities associated with an oblique shock wave are conveniently represented in the velocity-vector (hodograph) plane. For a given Mach number ahead of the shock wave, all possible velocity vectors behind the shock lie on a single curve.

Only the closed loop represents real shock waves with non-decreasing entropy, and forms Busemann's shock polar (fig. 3). Its equation is

$$v_2^2 = (V_1 - u_2)^2 \frac{u_2 - \frac{a_*^2}{V_1}}{\frac{2}{\gamma+1} V_1 + \frac{a_*^2}{V_1} - u_2} \quad (163)$$

Other forms of this equation convenient for computation are, given  $V_1$  and  $M_1$ ,

$$\begin{aligned} \left( \frac{v_2}{V_1} \right)^2 &= \left( 1 - \frac{u_2}{V_1} \right)^2 \frac{(M_1^2 - 1) - \frac{\gamma+1}{2} M_1^2 \left( 1 - \frac{u_2}{V_1} \right)}{1 + \frac{\gamma+1}{2} M_1^2 \left( 1 - \frac{u_2}{V_1} \right)} \\ &= \left( 1 - \frac{u_2}{V_1} \right)^2 \frac{5(M_1^2 - 1) - 6M_1^2 \left( 1 - \frac{u_2}{V_1} \right)}{5 + 6M_1^2 \left( 1 - \frac{u_2}{V_1} \right)} \end{aligned} \quad (164a)$$

given  $a_*$  and  $V_1$ ,

$$\begin{aligned} \left(\frac{V_2}{a_*}\right)^2 &= \left(\frac{V_1 - u_2}{a_* - a_*}\right)^2 \frac{\frac{V_1}{a_*} \frac{u_2}{a_*} - 1}{1 + \frac{2}{\gamma+1} \left(\frac{V_1}{a_*}\right)^2 - \frac{V_1}{a_*} \frac{u_2}{a_*}} \\ &= \left(\frac{V_1 - u_2}{a_* - a_*}\right)^2 \frac{\frac{6}{a_*} \left(\frac{V_1}{a_*} \frac{u_2}{a_*} - 1\right)}{5 \left(\frac{V_1}{a_*}\right)^2 - 6 \left(\frac{V_1}{a_*} \frac{u_2}{a_*} - 1\right)} \quad (164b) \end{aligned}$$

and given  $V_1$  and  $V_m$ ,

$$\begin{aligned} \left(\frac{v_2}{V_m}\right)^2 &= \left(\frac{V_1 - u_2}{V_m - V_m}\right)^2 \frac{\frac{V_1}{V_m} \frac{u_2}{V_m} - \frac{\gamma-1}{\gamma+1}}{\frac{2}{\gamma+1} \left(\frac{V_1}{V_m}\right)^2 + \frac{\gamma-1}{\gamma+1} - \frac{V_1}{V_m} \frac{u_2}{V_m}} \\ &= \left(\frac{V_1 - u_2}{V_m - V_m}\right)^2 \frac{\left(\frac{6}{V_m} \frac{V_1}{V_m} \frac{u_2}{V_m} - 1\right)}{5 \left(\frac{V_1}{V_m}\right)^2 - \left(6 \frac{V_1}{V_m} \frac{u_2}{V_m} - 1\right)} \quad (164c) \end{aligned}$$

The shock-wave angle  $\theta$  and wedge angle  $\delta$  are given in terms of the velocity components by

$$\tan \theta = \frac{V_1 - u_2}{v_2} = \frac{\bar{u}_1}{\bar{v}_1} \quad (165)$$

$$\tan \delta = \frac{v_2}{u_2} \quad (166)$$

The shock-wave angle  $\theta_*$  for sonic flow behind the shock is found (by setting  $M_2 = 1$  in eq. (132)) to be given by

$$\begin{aligned} \sin^2 \theta_* &= \frac{1}{4\gamma M_1^2} \{ (\gamma+1)M_1^2 - (3-\gamma) + \\ &\quad \sqrt{(\gamma+1)[(\gamma+1)M_1^4 - 2(3-\gamma)M_1^2 + (\gamma+9)]} \} \\ &= \frac{1}{7M_1^2} [3M_1^2 - 2 + \sqrt{3(3M_1^4 - 4M_1^2 + 13)}] \quad (167) \end{aligned}$$

The shock-wave angle  $\theta_{i_{max}}$  for maximum stream deflection behind the shock is given by

$$\begin{aligned} \sin^2 \theta_{i_{max}} &= \frac{1}{4\gamma M_1^2} \{ (\gamma+1) M_1^2 - 4 + \\ &\quad \sqrt{(\gamma+1) [(\gamma+1) M_1^4 + 8(\gamma-1) M_1^2 + 16]} \} \\ &= \frac{1}{7M_1^2} [3M_1^2 - 5 + \sqrt{3 (3M_1^4 + 4M_1^2 + 20)}] \quad (168) \end{aligned}$$

For small deflection angles (hence Mach numbers close to unity), the deflection angle (radians) for sonic flow behind the shock is given approximately in terms of the upstream Mach number by

$$\delta_* = \frac{1}{\sqrt{2}(\gamma+1)} \frac{(M_1^2 - 1)^{3/2}}{M_1^2} = 0.2946 \frac{(M_1^2 - 1)^{3/2}}{M_1^2} \quad (169)$$

The maximum stream deflection angle for a specified upstream Mach number is given approximately by

$$\delta_{i_{max}} = \frac{4}{3\sqrt{3}(\gamma+1)} \frac{(M_1^2 - 1)^{3/2}}{M_1^2} = 0.3208 \frac{(M_1^2 - 1)^{3/2}}{M_1^2} \quad (170)$$

In unsteady flow all the above relations are valid across a moving oblique shock wave if instantaneous velocities are measured relative to the shock.

## SUPERSONIC FLOW PAST WEDGES AND CONES

A shock wave forms ahead of any body in supersonic flight and remains fixed relative to the body if the flight is steady. It stands ahead of blunt shapes, but may be attached to pointed shapes.

Just at the tip of a pointed airfoil or body of revolution the flow is the same as for the initially tangent wedge or cone. The bow wave is attached at sufficiently high Mach numbers for a wedge of semivertex angle  $\delta$  less than  $\sin^{-1}(1/\gamma) = 45.6^\circ$  for  $\gamma = 7/5$ , and for a circular cone of semivertex angle  $\sigma$  less than  $57.5^\circ$  for  $\gamma = 1.405$ . Below these limits, the wave is attached above a minimum Mach number whose dependence upon nose angle is shown for wedges and cones in figure 4. (These values can be applied to pointed airfoils and bodies of revolution which are not concave.) Also shown in figure 4 are the slightly higher Mach numbers above which the velocity behind the shock wave is supersonic, and for the cone the still higher Mach number above which the flow is supersonic even at the surface. (For wedges these last two coincide.) For thin wedges, these Mach numbers are given approximately by equations (169) and (170).

### FLOW PAST WEDGES

If the bow shock wave is attached to a wedge, it is straight and the flow behind the shock consists of uniform streams parallel to either face of the wedge. The flow pattern above the upper face (fig. 5) may be regarded as obtained from the straight oblique shock-wave pattern of figure 2 by replacing the streamline behind the shock wave with a solid wall. Flow quantities are determined by the oblique-shock-wave relations, equations (115) to (170). As noted previously, table II can also be applied if  $M_1 \sin \theta$  is used in place of  $M_1$  in the first column.

The flows above and below the wedge are independent, so that inclined wedges can be treated if neither face exceeds the attachment angle shown in figure 4. However, if the angle of attack exceeds the semivertex angle, the flow over the upper (leeward) surface is given by a Prandtl-Meyer expansion (see fig. 4) rather than by the shock relations.

It is clear from the shock polar (fig. 3) that two different shock waves and flow patterns are theoretically possible for a given wedge and Mach number. However, it is believed that only the weaker shock wave (larger  $u_2$  and smaller  $\theta$ ) can occur attached to an isolated convex body.

Charts 2, 3, and 4 show the dependence of shock-wave angle, surface pressure coefficient, and downstream Mach number upon wedge angle for various free-stream Mach numbers.

### FLOW PAST CONES

If the bow shock wave is attached to an uninclined circular cone, the shock wave too has the form of a circular cone. Flow quantities are constant on all concentric conical surfaces lying between the shock wave and the body, and so depend upon only one space variable. The transition across the shock wave is governed by the oblique-shock relations,

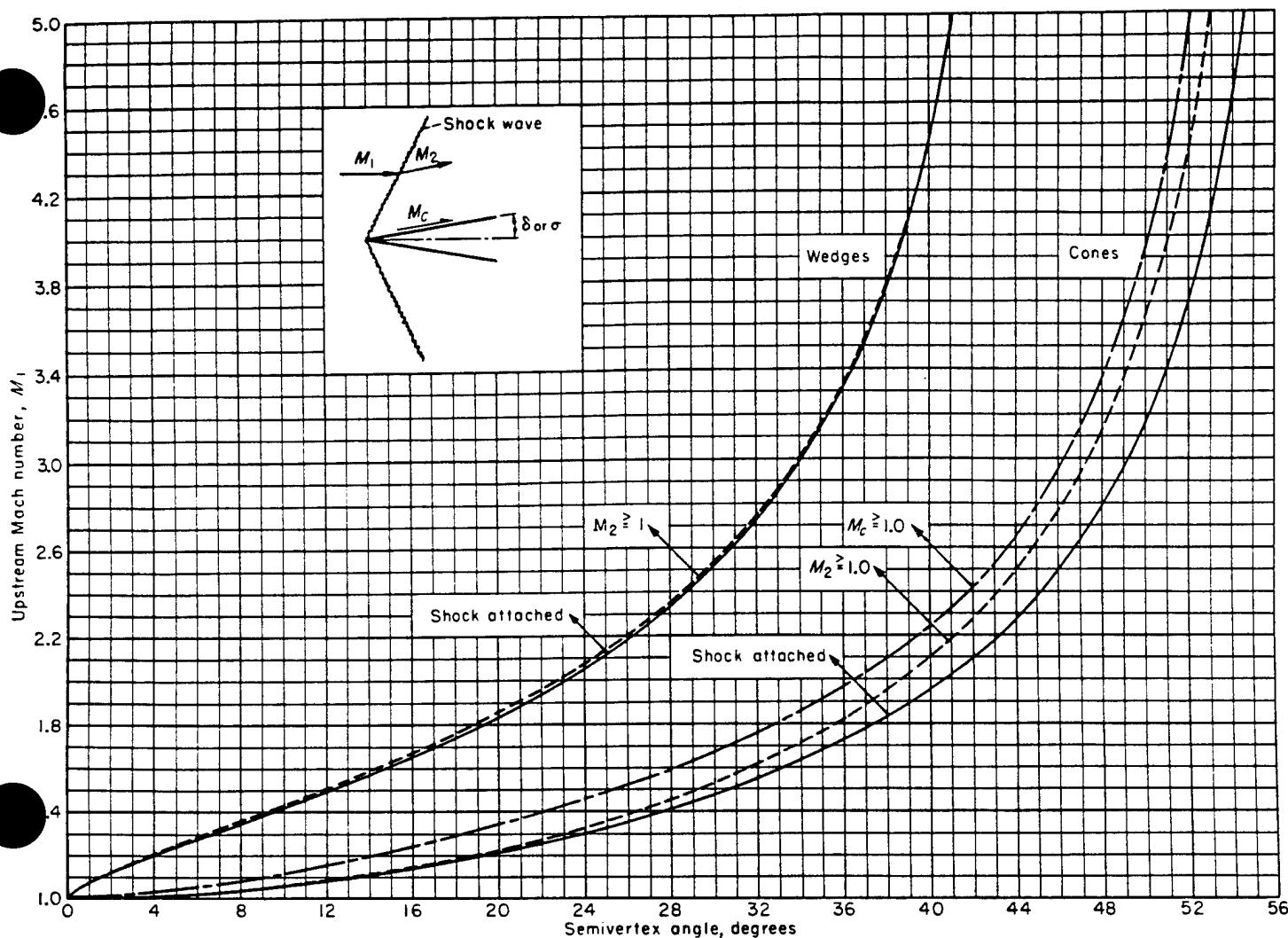


FIGURE 4.—Upstream Mach numbers for shock attachment and for supersonic flow behind shock wave on wedges and cones, and for supersonic flow at surface of cones.

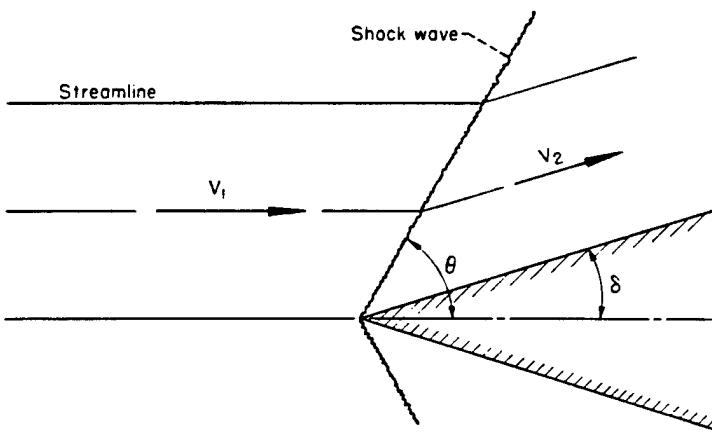


FIGURE 5.—Flow past a wedge.

and is followed by a continuous isentropic compression to free conditions, as indicated in figure 6. The flow quantities have been extensively tabulated in reference 6 for  $\gamma = 1.405$  and for  $\gamma = 4/3$ . As in the case of wedges, two solutions exist for each cone and Mach number, but it is believed that only the weaker shock wave can occur on an isolated convex body. Charts 5, 6, and 7 show the dependence of shock-wave angle, surface-pressure coefficient, and

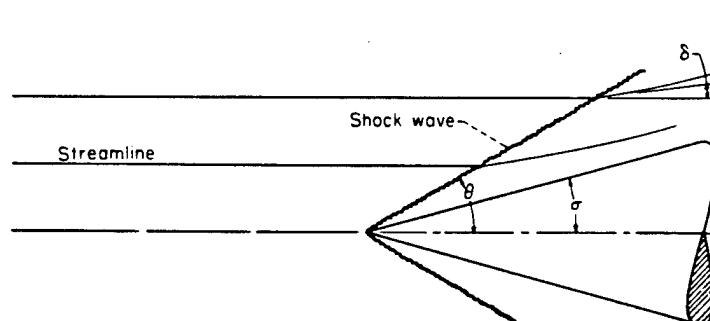


FIGURE 6.—Flow past a cone.

surface Mach number on cone semivertex angle for various free-stream Mach numbers.

The effects of slightly inclining a cone have been considered by Stone (ref. 13) and numerical results are tabulated in reference 14. Chart 8 shows the variation with Mach number of the initial slope of the normal-force curve for various cone angles. Stone has also sought an approximation for larger inclinations by retaining squares as well as first powers of angle of attack (ref. 15), and numerical results have been tabulated (ref. 16); however, these results are not free of error (see refs. 17 and 18).

### PRANDTL-MEYER EXPANSION

A uniform two-dimensional supersonic stream flowing over a convex bend expands isentropically. Convenient relations are found by considering the special case of a stream at Mach number unity flowing around a sharp corner (fig. 7).

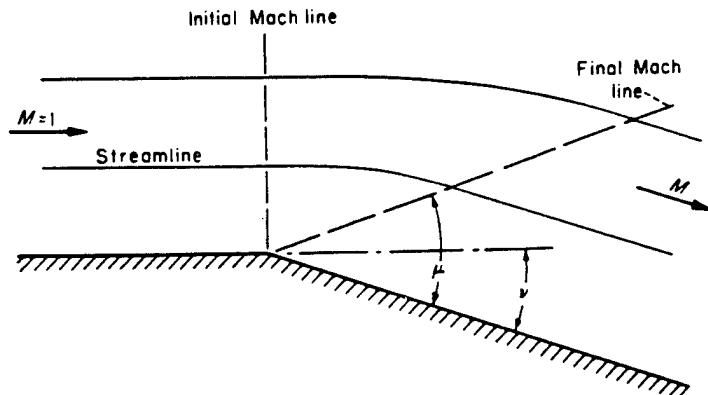


FIGURE 7.—Prandtl-Meyer expansion around a corner.

For a perfect gas, the Prandtl-Meyer angle  $\nu$  through which the stream turns in expanding from  $M=1$  to a supersonic Mach number  $M$  is

$$\nu = \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1} (M^2 - 1)} - (90^\circ - \mu) \quad (171a)$$

$$= \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1} (M^2 - 1)} - \cos^{-1} \frac{1}{M} \quad (171b)$$

$$= \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1} (M^2 - 1)} - \tan^{-1} \sqrt{M^2 - 1} \quad (171c)$$

(For  $\gamma = 7/5$ ,  $\sqrt{\frac{\gamma+1}{\gamma-1}} = 2.4495$ , and  $\sqrt{\frac{\gamma-1}{\gamma+1}} = 0.40825$ .) The maximum expansion angle, for  $M = \infty$ , is

$$\nu_{max} = \left( \sqrt{\frac{\gamma+1}{\gamma-1}} - 1 \right) \times 90^\circ = 130.45^\circ \text{ for } \gamma = 7/5 \quad (172)$$

The ratio of static to total pressure, corresponding to Mach number  $M$  is given by

$$\left( \frac{p}{p_t} \right)^{\frac{\gamma-1}{\gamma}} = \frac{1}{\gamma+1} \left\{ 1 + \cos \left[ 2 \sqrt{\frac{\gamma-1}{\gamma+1}} (\nu + 90^\circ - \mu) \right] \right\} \quad (173a)$$

$$= \frac{1}{\gamma+1} \left\{ 1 + \cos \left[ 2 \sqrt{\frac{\gamma-1}{\gamma+1}} \left( \nu + \cos^{-1} \frac{1}{M} \right) \right] \right\} \quad (173b)$$

$$= \frac{1}{\gamma+1} \left\{ 1 + \cos \left[ 2 \sqrt{\frac{\gamma-1}{\gamma+1}} \left( \nu + \tan^{-1} \sqrt{M^2 - 1} \right) \right] \right\} \quad (173c)$$

which falls to zero as  $\nu \rightarrow \nu_{max}$ . Numerical values of  $\nu$ ,  $\mu$ , and  $p/p_t$  are given in table II as functions of  $M$ .

These relations and the values in table II apply to a uniform stream flowing past any convex surface in the ab-

sence of external disturbances. (They also give a very good approximation at all Mach numbers when, as on an aircraft, external disturbances arise only from interaction with a shock wave, and are disregarded.) If flow quantities known at one point, the values at any second point can be read from table II by identifying the change in flow angle between the two points with  $\Delta\nu = \nu_2 - \nu_1$ , as indicated in figure 8.

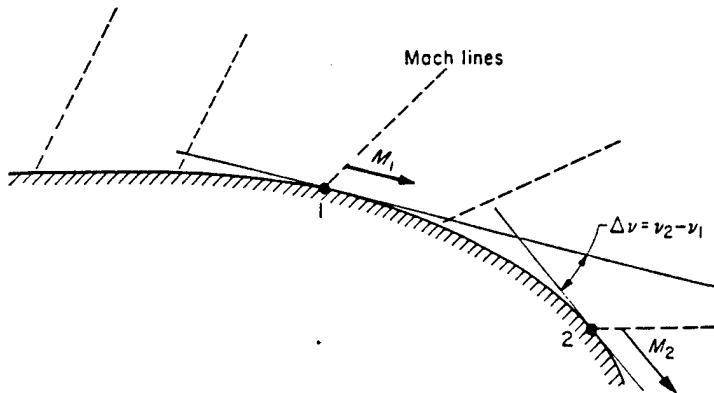


FIGURE 8.—Prandtl-Meyer expansion over a convex surface.

For expansions through small angles  $\Delta\nu$ , the ratio of final to initial static pressures is given by the following series ( $\Delta\nu$  in radians):

$$\begin{aligned} \frac{p_2}{p_1} = 1 &- \frac{\gamma M_1^2}{\sqrt{M_1^2 - 1}} (\Delta\nu) + \gamma M_1^2 \frac{(\gamma+1) M_1^4 - 4 (M_1^2 - 1)}{4(M_1^2 - 1)^2} (\Delta\nu)^2 \\ &- \frac{\gamma M_1^2}{2(M_1^2 - 1)^{1/2}} \left[ \frac{\gamma+1}{6} M_1^8 - \frac{5+7\gamma-2\gamma^2}{6} M_1^6 + \right. \\ &\left. \frac{5}{3} (\gamma+1) M_1^4 - 2 M_1^2 + \frac{4}{3} \right] (\Delta\nu)^3 + \dots \quad (174) \end{aligned}$$

Up to and including the term in  $(\Delta\nu)^2$  this series is identical with that for compression through an oblique shock wave (eq. (151) with  $\delta = -\Delta\nu$ ).

### IMPERFECT-GAS EFFECTS

Methods for calculating the flow of a calorically imperfect, thermally imperfect gas and a calorically imperfect, thermally perfect gas at temperatures up to 5000° R are described in this section. The equations presented are in substantially the same form as those given in references 7 and 8. Effects of gaseous imperfections, such as molecular dissociation, which become important at temperatures greater than about 5000° R are not considered.

Atmospheric and wind-tunnel air flows are of primary concern here. In such flows air generally exhibits only caloric imperfections to any appreciable degree. Consequently, numerical results are presented only for the flow of a calorically imperfect, thermally perfect diatomic gas.

### THERMODYNAMICS

#### EQUATIONS OF STATE

The thermal equation of state used here for a calorically and thermally imperfect gas is the Berthelot equation

(5)). The thermal equation of state used for a calorically imperfect, thermally perfect gas is equation (2). The caloric equation of state used for a calorically and thermally perfect gas is equation (8a). The caloric equation of state used for a calorically imperfect, thermally perfect gas is equation (8b).

## SPECIFIC HEATS

The assumption of a simple harmonic vibrator is used to account for the contribution of the vibrational heat capacity to the specific heats. The equations for the specific heats at constant volume and constant pressure, respectively, are (see ref. 7)

$$c_v = (c_v)_{\text{perf}} \left\{ 1 + (\gamma_{\text{perf}} - 1) \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \right] \right\} \quad (175)$$

$$c_p = (c_p)_{\text{perf}} \left\{ 1 + (\gamma_{\text{perf}} - 1) \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} \right] \right\} \text{ [therm perf]} \quad (176)$$

$$c_p = (c_p)_{\text{perf}} \left\{ 1 + \frac{\gamma_{\text{perf}} - 1}{\gamma_{\text{perf}}} \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \left( 1 + \frac{1}{\frac{1-b\rho}{(1-b\rho)^2} - \frac{2c\rho}{RT^2}} \right) \right] \right\} \quad (177)$$

$$(c_p)_{\text{perf}} \left\{ 1 + \frac{\gamma_{\text{perf}} - 1}{\gamma_{\text{perf}}} \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} \right] \right\} \text{ [therm perf]} \quad (178)$$

The ratio of specific heats is then

$$\gamma = \gamma_{\text{perf}} \times \left[ \frac{1 + \frac{\gamma_{\text{perf}} - 1}{\gamma_{\text{perf}}} \left\{ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \left[ 1 + \frac{2-b\rho}{1-b\rho} + \frac{c\rho}{2RT^2} \right] \right\}}{1 + (\gamma_{\text{perf}} - 1) \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \right]} \right] \quad (179)$$

or, for a thermally perfect gas,

$$\gamma = 1 + \frac{\gamma_{\text{perf}} - 1}{1 + (\gamma_{\text{perf}} - 1) \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} \right]} \text{ [therm perf]} \quad (180)$$

The following values of  $\gamma$  are for temperatures from 400° R to 5000° R, with  $\theta=5500° R$  (see ref. 7). For engineering purposes, these are a satisfactory approximation for air.

VARIATION OF RATIO OF SPECIFIC HEATS WITH TEMPERATURE			
T, °R	$\gamma$	T, °R	$\gamma$
500	1.400	1300	1.361
600	1.399	1400	1.355
700	1.396	1500	1.349
800	1.392	1600	1.344
900	1.387	1700	1.339
1000	1.381	1800	1.335
1100	1.375	1900	1.331
1200	1.368	2000	1.328
		2200	1.322
		2400	1.317
		2600	1.313
		2800	1.309
		3000	1.306
		3500	1.301
		4000	1.298
		4500	1.295
		5000	1.294

## CONTINUOUS ONE-DIMENSIONAL FLOW

## BASIC EQUATIONS AND DEFINITIONS

Basic equations pertinent to this section are equations (26), (27), (28), (29), (30), and (31). The equations for the speed of sound are (see ref. 7)

$$a^2 = RT \left\{ \frac{1}{(1-b\rho)^2} - \frac{2c\rho}{RT^2} + \frac{(\gamma_{\text{perf}} - 1) \left( \frac{c\rho}{RT^2} + \frac{1}{1-b\rho} \right)^2}{1 + (\gamma_{\text{perf}} - 1) \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \right]} \right\} \quad (181)$$

and

$$a^2 = RT \left\{ 1 + \frac{\gamma_{\text{perf}} - 1}{\left[ 1 + (\gamma_{\text{perf}} - 1) \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} \right]} \right\} \text{ [therm perf]} \quad (182)$$

## INTEGRATED FORMS OF ENERGY EQUATION

The integrated forms of the energy equation are (see ref. 7)

$$V^2 = 2RT_i \left[ \frac{1 - \frac{T}{T_i}}{\gamma_{\text{perf}} - 1} + \frac{\theta}{T_i} \left( \frac{1}{e^{\theta/T_i} - 1} - \frac{1}{e^{\theta/T} - 1} \right) + \frac{2c}{RT_i} \left( \frac{\rho}{T} - \frac{\rho_i}{T_i} \right) + \frac{1}{RT_i} \left( \frac{p_i - p}{\rho_i - \rho} \right) \right] \text{ [adiab]} \quad (183)$$

and

$$V^2 = 2RT_i \left[ \frac{\gamma_{\text{perf}}}{\gamma_{\text{perf}} - 1} \left( 1 - \frac{T}{T_i} \right) + \frac{\theta}{T_i} \left( \frac{1}{e^{\theta/T_i} - 1} - \frac{1}{e^{\theta/T} - 1} \right) \right] \quad (184)$$

$$\left. \frac{\theta}{T_i} \left( \frac{1}{e^{\theta/T_i} - 1} - \frac{1}{e^{\theta/T} - 1} \right) \right] \text{ [adiab, therm perf]} \quad (184)$$

In terms of Mach number these equations become, respectively,

$$M^2 = \frac{2T_i \left[ \frac{1}{\gamma_{\text{perf}} - 1} + \frac{\theta}{T_i} \left( \frac{1}{e^{\theta/T_i} - 1} - \frac{1}{e^{\theta/T} - 1} \right) + \frac{2c}{RT_i} \left( \frac{\rho}{T} - \frac{\rho_i}{T_i} \right) + \frac{1}{RT_i} \left( \frac{p_i}{\rho_i} - \frac{p}{\rho} \right) \right]}{T \left\{ \frac{1}{(1 - b\rho)^2} - \frac{2c\rho}{RT^2} + \frac{(\gamma_{\text{perf}} - 1) \left( \frac{c\rho}{RT^2} + \frac{1}{1 - b\rho} \right)^2}{1 + (\gamma_{\text{perf}} - 1) \left[ \left( \frac{\theta}{T} \right)^2 \frac{e^{\theta/T}}{(e^{\theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \right]} \right\}} \quad [\text{adiab}] \quad (185)$$

and

$$M^2 = \frac{2T_i}{\gamma T} \left[ \frac{\gamma_{\text{perf}}}{\gamma_{\text{perf}} - 1} \left( 1 - \frac{T}{T_i} \right) + \frac{\theta}{T_i} \left( \frac{1}{e^{\theta/T_i} - 1} - \frac{1}{e^{\theta/T} - 1} \right) \right] \quad [\text{adiab, therm perf}] \quad (186)$$

where  $\gamma$  is given by equation (180).

The variations of  $\frac{\left(\frac{V}{a_*}\right)_{\text{therm perf}}}{\left(\frac{V}{a_*}\right)_{\text{perf}}}$  and  $\frac{\left(\frac{T}{T_i}\right)_{\text{therm perf}}}{\left(\frac{T}{T_i}\right)_{\text{perf}}}$  with Mach number for several values of total temperature  $T_i$  are given in charts 9 and 10.

#### PRESSURE AND DENSITY RELATIONS

For isentropic flow, the relations between density and temperature are (see ref. 7)

$$\left( \frac{\rho}{\rho_i} \right) \left( \frac{1 - b\rho_i}{1 - b\rho} \right) = \left( \frac{e^{\theta/T_i} - 1}{e^{\theta/T} - 1} \right) \left( \frac{T}{T_i} \right)^{\frac{1}{\gamma_{\text{perf}} - 1}} \exp \left[ \frac{c\rho_i}{RT_i^2} - \frac{c\rho}{RT^2} + \left( \frac{\theta}{T} \right) \frac{e^{\theta/T}}{e^{\theta/T} - 1} - \left( \frac{\theta}{T_i} \right) \frac{e^{\theta/T_i}}{e^{\theta/T_i} - 1} \right] \quad [\text{isen}] \quad (187)$$

and, for a thermally perfect gas,

$$\frac{\rho}{\rho_i} = \left( \frac{e^{\theta/T_i} - 1}{e^{\theta/T} - 1} \right) \left( \frac{T}{T_i} \right)^{\frac{1}{\gamma_{\text{perf}} - 1}} \exp \left[ \left( \frac{\theta}{T} \right) \frac{e^{\theta/T}}{e^{\theta/T} - 1} - \left( \frac{\theta}{T_i} \right) \frac{e^{\theta/T_i}}{e^{\theta/T_i} - 1} \right] \quad [\text{isen, therm perf}] \quad (188)$$

The variation of  $\frac{\left(\frac{\rho}{\rho_i}\right)_{\text{therm perf}}}{\left(\frac{\rho}{\rho_i}\right)_{\text{perf}}}$  with Mach number for several total temperatures is presented in chart 11.

$$\frac{p}{p_i} = \left( \frac{e^{\theta/T_i} - 1}{e^{\theta/T} - 1} \right) \left( \frac{T}{T_i} \right)^{\frac{1}{\gamma_{\text{perf}} - 1}} \exp \left[ \left( \frac{\theta}{T} \right) \frac{e^{\theta/T}}{e^{\theta/T} - 1} - \left( \frac{\theta}{T_i} \right) \frac{e^{\theta/T_i}}{e^{\theta/T_i} - 1} \right] \quad [\text{isen, therm perf}] \quad (189)$$

The relation between dynamic and static pressure for a thermally imperfect gas can be obtained by a trial-and-error procedure using equations (5), (31a), (183), and (187). The relation between dynamic and static pressure for a thermally perfect gas can be obtained with equations (31b) and (186), and is

$$\frac{q}{p} = \frac{\gamma_{\text{perf}}}{\gamma_{\text{perf}} - 1} \left( \frac{T_i}{T} - 1 \right) + \frac{\theta}{T} \left( \frac{1}{e^{\theta/T_i} - 1} - \frac{1}{e^{\theta/T} - 1} \right) \quad [\text{adiab, therm perf}] \quad (190)$$

The variations of  $\frac{\left(\frac{p}{p_i}\right)_{\text{therm perf}}}{\left(\frac{p}{p_i}\right)_{\text{perf}}}$  and  $\frac{\left(\frac{q}{p_i}\right)_{\text{therm perf}}}{\left(\frac{q}{p_i}\right)_{\text{perf}}}$  with Mach

number for several total temperatures are given in charts 12 and 13.

#### STREAM-TUBE-AREA RELATIONS

The stream-tube-area relation is given by equation (79) or, in more convenient form,

$$\frac{A}{A_*} = \frac{\rho_* a_*}{\rho a M} \quad (191)$$

This ratio can be evaluated for a thermally imperfect gas with the aid of equations (187), (181), (5), and (185), and for a thermally perfect gas with the aid of equations (188)

(182), and (186). The variation of  $\frac{\left(\frac{A}{A_*}\right)_{\text{therm perf}}}{\left(\frac{A}{A_*}\right)_{\text{perf}}}$  with

number for several values of total temperature is presented in chart 14.

<sup>1</sup> In this, as in many of the cases to be presented, no direct solution for flow properties is possible if the gas exhibits both thermal and caloric imperfections. Approximate solutions of this type can be obtained, however, if the degree of imperfection is small (see ref. 7).

## NORMAL SHOCK WAVES

The requirements for conservation of mass, momentum, and energy across a normal shock wave are given by equations (84), (85), and (86a). The energy relation can be written

$$\frac{u_2^2 - u_1^2}{2} + \frac{R}{\gamma_{\text{perf}} - 1} (T_2 - T_1) - \left( \frac{2c\rho_2}{T_2} - \frac{2c\rho_1}{T_1} \right) + \left( \frac{p_2}{\rho_2} - \frac{p_1}{\rho_1} \right) + R\Theta \left( \frac{1}{e^{\Theta/T_2} - 1} - \frac{1}{e^{\Theta/T_1} - 1} \right) = 0 \quad [\text{adiab}] \quad (192)$$

or, for a thermally perfect gas,

$$\frac{u_2^2 - u_1^2}{2} + \left( \frac{\gamma_{\text{perf}}}{\gamma_{\text{perf}} - 1} \right) R(T_2 - T_1) + R\Theta \left( \frac{1}{e^{\Theta/T_2} - 1} - \frac{1}{e^{\Theta/T_1} - 1} \right) = 0 \quad [\text{adiab, therm perf}] \quad (193)$$

No explicit equation has been found to relate the temperature downstream of a normal shock wave in thermally imperfect air to the upstream conditions. A trial-and-error procedure, starting with assumed values of  $\rho_2$  and  $T_2$  and involving equations (5), (84), (85), and (192), can be used to determine the downstream temperature.

For the flow of a thermally perfect gas, the simultaneous solution of equations (84), (85), (193), and (2) yields the following relation from which the temperature behind the shock wave can be found:

$$\left( u_1 + \frac{RT_1}{u_1} \right)^2 - \left( u_1 + \frac{RT_1}{u_1} \right) \sqrt{\left( u_1 + \frac{RT_1}{u_1} \right)^2 - 4RT_2} - 2RT_2 - 4R\Theta \left( \frac{1}{e^{\Theta/T_2} - 1} - \frac{1}{e^{\Theta/T_1} - 1} \right) = 0 \quad [\text{adiab, therm perf}] \quad (194)$$

Since the total temperature  $T_t$  remains constant across a shock wave, other flow parameters behind the shock wave can be found with the aid of previously presented one-dimensional flow relations. The variations of

$$\frac{\left( \frac{T_2}{T_1} \right)_{\text{therm perf}}}{\left( \frac{T_2}{T_1} \right)_{\text{perf}}}, \frac{\left( \frac{\rho_2}{\rho_1} \right)_{\text{therm perf}}}{\left( \frac{\rho_2}{\rho_1} \right)_{\text{perf}}}, \frac{\left( \frac{p_1}{p_{t_2}} \right)_{\text{therm perf}}}{\left( \frac{p_1}{p_{t_2}} \right)_{\text{perf}}}, \\ \frac{\left( \frac{p_2}{p_1} \right)_{\text{therm perf}}}{\left( \frac{p_2}{p_1} \right)_{\text{perf}}}, \frac{M_{2\text{therm perf}}}{M_{2\text{perf}}}, \text{ and } \frac{\left( \frac{p_{t_2}}{p_{t_1}} \right)_{\text{therm perf}}}{\left( \frac{p_{t_2}}{p_{t_1}} \right)_{\text{perf}}}$$

upstream Mach number for several total temperatures are presented in charts 15 through 20, respectively.

## OBLIQUE SHOCK WAVES

For a thermally imperfect gas, no simple equations can be found to relate the values of the flow parameters across oblique shock waves. In general, trial-and-error procedure, starting with assumed values of  $\rho_2$  and  $T_2$ , and involving the relations for the conservation of mass, momentum, and energy, must be used. (See eqs. (115), (116), (117), and (118a) as well as equations (5) and (183).) For a thermally perfect gas, the Mach number downstream of an oblique shock wave can be found with the aid of the energy equation (see eqs. (118a) and (186)), thus

$$M_2^2 = \frac{2T_1}{\gamma_2 T_2} \left[ \frac{\gamma_1 M_1^2}{2} + \left( \frac{\gamma_{\text{perf}}}{\gamma_{\text{perf}} - 1} \right) \left( 1 - \frac{T_2}{T_1} \right) + \frac{\Theta}{T_1} \left( \frac{1}{e^{\Theta/T_1} - 1} - \frac{1}{e^{\Theta/T_2} - 1} \right) \right] \quad [\text{adiab, therm perf}] \quad (195)$$

where  $\gamma_1$  and  $\gamma_2$  are the functions of  $T_1$  and  $T_2$ , respectively, given by equation (180). The pressure ratio across the shock is given by

$$\frac{p_1}{p_2} = \frac{1}{2} \left[ (1 + \gamma_2 M_2^2) - \frac{T_1}{T_2} (1 + \gamma_1 M_1^2) + \sqrt{\left[ (1 + \gamma_2 M_2^2) - \frac{T_1}{T_2} (1 + \gamma_1 M_1^2) \right]^2 + 4 \frac{T_1}{T_2}} \right] \quad [\text{adiab, therm perf}] \quad (196)$$

The density ratio can be determined from the equation of state (eq. (2)) with the aid of the pressure and temperature ratios. The shock-wave and deflection angles are given by (see ref. 8)

$$\sin^2 \theta = \frac{\left( \frac{\gamma_2}{\gamma_1} \right) \left( \frac{T_2}{T_1} \right) \left( \frac{M_2}{M_1} \right)^2 - 1}{\left( \frac{p_1}{p_2} \right)^2 - 1} \quad [\text{adiab, therm perf}] \quad (197)$$

and

$$\cot \delta = \tan \theta \left( \frac{\gamma_1 M_1^2}{\frac{p_2}{p_1} - 1} \right) \quad [\text{adiab, therm perf}] \quad (198)$$

respectively.

The variation of  $\theta$  with  $\delta$  for various values of  $M_1$  and  $T_1$  is presented in chart 21. In addition, the variations of

$\frac{(M_2)_{\text{therm perf}}}{(M_2)_{\text{perf}}}$  and  $\frac{\left( \frac{p_2 - p_1}{q_1} \right)_{\text{therm perf}}}{\left( \frac{p_2 - p_1}{q_1} \right)_{\text{perf}}}$  with  $\delta$  for various  $M_1$  and  $T_1$  are presented in charts 22 and 23.

Values of the ratios

$$\frac{p_2}{p_1}, \frac{\rho_2}{\rho_1}, \frac{T_2}{T_1}, \frac{p_{t_2}}{p_{t_1}}$$

for the flow of a thermally perfect gas across an oblique shock wave can be determined from the normal-shock relations,

provided that  $M_1 \sin \theta$  is used instead of  $M_1$  and that the static temperature  $T_1$  just upstream of the shock wave is the same for the oblique shock wave as for the normal shock wave.

#### PRANDTL-MEYER EXPANSION

The Prandtl-Meyer angle for the flow of an imperfect gas can be found by graphically integrating the equation (see ref. 8)

$$\nu = - \int_{p_1}^p \frac{dp}{\rho V^2 \tan \mu} \quad [\text{isen}] \quad (199)$$

The relations between  $p$ ,  $\rho$ ,  $V$ , and  $\mu$  can be found with the

aid of equations (5), (187), (183), and (185). For a thermally perfect gas this equation becomes (see, again, ref. 8)

$$\nu = - \int_{p_1}^p \frac{\sin 2\mu}{2\gamma p} dp \quad [\text{isen, therm perf}] \quad (200)$$

The relations between  $\gamma$ ,  $p$ , and  $\mu$  can be found with the aid of equations (180), (189), and (186) using the temperature as a parameter. The graphical integration of equation (200) has been carried out, and the variations of  $\nu_{\text{therm perf}}$  and  $\frac{\nu_{\text{therm perf}}}{\nu_{\text{perf}}}$  with Mach number for various values of total temperature are presented in chart 24.

## APPENDIX A

### VISCOSITY AND THERMODYNAMIC CONSTANTS FOR AIR

#### VISCOSITY

The viscosity of air is nearly independent of pressure; the variation with absolute temperature, between temperatures of about 300° R and 900° R, may be approximated by the formula

$$\frac{\mu}{\mu_r} = \left( \frac{T}{T_r} \right)^{0.76} \quad (A1)$$

For a wider range of temperatures, between about 180° R and 3400° R, Sutherland's formula (see ref. 19) is more accurate:

$$\frac{\mu}{\mu_r} = \frac{T_r + 198.6}{T + 198.6} \left( \frac{T}{T_r} \right)^{3/2} \quad (A2)$$

The viscosity of air, as determined from this relation, may be expressed as

$$\mu = 2.270 \frac{T^{3/2}}{T + 198.6} \times 10^{-8} \frac{\text{lb sec}}{\text{ft}^2} \quad (A3)$$

This latter equation has been employed in the calculations of Reynolds number (chart 25).

#### THERMODYNAMIC CONSTANTS

The value of  $\gamma$  employed for air, when treated as a completely perfect gas, is 7/5. This simple value, which has been employed in table I, table II, charts 1 to 4, and chart 25, is a good approximation to the more precise values obtained from spectroscopic measurements (see ref. 20). Values of  $c_p$ ,  $c_v$ , and  $R$  for air, consistent with the approximation  $\gamma = 7/5$ , are

$$c_p = 6006 \text{ ft}^2/\text{sec}^2 \text{ °R}$$

$$c_v = 4290 \text{ ft}^2/\text{sec}^2 \text{ °R}$$

$$R = 1716 \text{ ft}^2/\text{sec}^2 \text{ °R}$$

## APPENDIX B

### REYNOLDS NUMBER

Reynolds number is defined as

$$R = \frac{\rho V l}{\mu} \quad (B1)$$

For sea-level conditions,

$$R \cong 10,000 \quad (V \text{ in mph}) \quad (l \text{ in ft}) \quad (B2)$$

In a wind tunnel (subsonic or supersonic), if isentropic expansion is assumed from a total pressure  $p_t$  and equation

(A2) is used for the variation of viscosity with temperature, the Reynolds number per unit reference length is given by

$$R = \frac{p_t M}{\mu_r} \sqrt{\frac{\gamma}{(\gamma-1)c_v T_i}} \left( \frac{T_i}{T} \right)^{\frac{\gamma-2}{\gamma-1}} \frac{T}{T_i} + \frac{198.6}{1 + \frac{198.6}{T_i}} \quad [\text{perf}] \quad (B3)$$

The Reynolds number per unit length for  $p_t = 1$  psia has been plotted in chart 25 as a function of  $M$  for various total temperatures  $T_i$ .

## APPENDIX C

### PRESSURE CONVERSION FACTORS AND CONSTANTS

Multiply by to obtain	lb in. <sup>2</sup>	lb ft <sup>2</sup>	in. H <sub>2</sub> O at 70° F	in. Hg at 70° F	cm. Hg at 70° F	Standard atmos- pheres
lb/in. <sup>2</sup>	1	0.006944	0.03607	0.4892	0.1926	14.70
lb/ft <sup>2</sup>	144	1	5.194	70.45	27.74	2117
in. H <sub>2</sub> O (70° F)	27.73	.1925	1	13.56	5.340	407.6
in. Hg (70° F)	2.044	.01420	.07373	1	.3937	30.05
cm. Hg (70° F)	5.192	.03605	.1873	2.540	1	76.33
Standard atmospheres	.06804	.0004725	.002453	.03328	.01310	1

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## TABLES

The tables that follow contain numerical values for certain quantities often required for the solution of problems in compressible flow. The symbols used in these tables are the same as those used in the preceding sections. For convenience, however, the symbols are redefined at the end of table II.

To conserve space, a modified computing-machine notation has been adopted to indicate the position of the decimal point in the tabulated quantities. The location of the decimal point is governed by the following rules:

- (a) A group of digits followed by  $_{-n}$  indicates that the decimal point should be n places to the left of the first digit.

Example: .3268  $_{-3} = .0003268$

- (b) A group of digits followed by  $_{+n}$  indicates that the decimal point should be n places to the right of the last digit.

Example: 3268  $_{+3} = 3,268,000$

- (c) A group of digits without a suffix indicates that the decimal point is correctly located as printed.

## TABLE I.—SUBSONIC FLOW

The ratios given by equations (43), (44), (45), (48), (50), and (83) are given as functions of Mach number. If, at a point in an isentropic flow, any one of these ratios or the Mach number is known, then all other ratios for that point can be read or interpolated from the table. In addition, the parameter  $\beta = \sqrt{M^2 - 1}$ , which is sometimes more convenient to use than the Mach number itself, is also tabulated.

## TABLE II.—SUPERSONIC FLOW

The ratios given in table I for subsonic flow are also given in table II for supersonic flow. The Mach angle  $\mu$  and the Prandtl-Meyer angle  $\nu$  are also given as functions of Mach number. In addition to these point functions for isentropic flow, the normal-shock relations given by equations (93), (94), (95), (96), (99), and (100) are tabulated as functions of the Mach number  $M_1$  ahead of the shock wave. Although these values are for normal shock waves, the values of  $p_2/p_1$ ,  $\rho_2/\rho_1$ ,  $T_2/T_1$ , and  $p_{t_2}/p_{t_1}$  may also be used for oblique shock waves, provided  $M_1 \sin \theta$  is used instead of  $M_1$  in the first column.

TABLE I.—SUBSONIC FLOW

 $\gamma = 7/5$ 

<i>M</i>	$\frac{p}{p_i}$	$\frac{\rho}{\rho_i}$	$\frac{T}{T_i}$	$\beta$	$\frac{q}{p_i}$	$\frac{A}{A_*}$	$\frac{U}{a_*}$	<i>M</i>	$\frac{p}{p_i}$	$\frac{\rho}{\rho_i}$	$\frac{T}{T_i}$	$\beta$	$\frac{q}{p_i}$	$\frac{A}{A_*}$	$\frac{U}{a_*}$		
0	1.0000	1.0000	1.0000	1.0000	0	—	—	0	0.50	0.8430	0.8852	0.9524	0.8660	0.1475	1.3398	0.53452	
.01	.9999	1.0000	1.0000	1.0000	.7000	.57	.8738	.01095	.51	.8374	.8809	.9506	.8602	.1525	1.3212	.54469	
.02	.9997	.9998	.9999	.9998	.2799	.28	.9421	.02191	.52	.8317	.8766	.9487	.8542	.1574	1.3034	.55483	
.03	.9994	.9996	.9997	.9996	.9995	.6296	.19	.3005	.03286	.53	.8259	.8723	.9468	.8480	.1624	1.2865	.56493
.04	.9989	.9992	.9997	.9992	.1119	.14	.4815	.04381	.54	.8201	.8679	.9449	.8417	.1674	1.2703	.57501	
.05	.9983	.9986	.9995	.9987	.1747	.11	.5914	.05476	.55	.8142	.8634	.9430	.8352	.1724	1.2550	.58506	
.06	.9975	.9932	.9993	.9932	.2514	.9	.6659	.06570	.56	.8082	.8589	.9410	.8285	.1774	1.2403	.59307	
.07	.9966	.9976	.9990	.9975	.3418	.8	.2915	.07664	.57	.8022	.8544	.9390	.8216	.1825	1.2263	.60305	
.08	.9955	.9968	.9987	.9988	.4460	.7	.2616	.08758	.58	.7962	.8498	.9370	.8146	.1875	1.2130	.61301	
.09	.9944	.9960	.9984	.9959	.5638	.6	.4613	.09851	.59	.7901	.8451	.9349	.8074	.1925	1.2003	.62192	
.10	.9930	.9950	.9980	.9950	.6951	.5	.8218	.10944	.60	.7840	.8405	.9328	.8000	.1976	1.1882	.63481	
.11	.9916	.9940	.9976	.9919	.8149	.4	.2992	.12035	.61	.7778	.8357	.9307	.7924	.2026	1.1767	.64466	
.12	.9900	.9928	.9971	.9928	.9979	.3	.4863	.13126	.62	.7716	.8310	.9286	.7846	.2076	1.1657	.65445	
.13	.9883	.9916	.9966	.9915	.1169	.2	.4969	.14217	.63	.7654	.8262	.9265	.7766	.2127	1.1552	.66427	
.14	.9864	.9903	.9961	.9902	.1353	.1	.4824	.15306	.64	.7591	.8213	.9243	.7684	.2177	1.1452	.67402	
.15	.9844	.9888	.9955	.9887	.1550	—	.9103	.16395	.65	.7528	.8164	.9221	.7599	.2227	1.1356	.68374	
.16	.9823	.9873	.9949	.9871	.1700	—	.6727	.17482	.66	.7465	.8115	.9199	.7513	.2276	1.1265	.69142	
.17	.9800	.9857	.9943	.9854	.1933	—	.4635	.18569	.67	.7401	.8066	.9176	.7424	.2326	1.1179	.70307	
.18	.9776	.9840	.9936	.9837	.2217	—	.2779	.19654	.68	.7338	.8016	.9153	.7332	.2375	1.1097	.71268	
.19	.9751	.9822	.9818	.9818	.2464	—	.3.123	.20739	.69	.7274	.7966	.9131	.7238	.2424	1.1018	.72225	
.20	.9725	.9803	.9821	.9795	.2723	—	.2.9635	.21822	.70	.7209	.7916	.9107	.7141	.2473	1.0944	.73179	
.21	.9697	.9783	.9913	.9777	.2991	—	.2.8293	.22904	.71	.7145	.7865	.9084	.7042	.2521	1.0873	.74129	
.22	.9668	.9762	.9904	.9755	.3276	—	.2.7076	.24944	.72	.7080	.7814	.9061	.6940	.2569	1.0806	.75076	
.23	.9638	.9740	.9895	.9732	.3569	—	.2.5988	.25633	.73	.7016	.7763	.9037	.6834	.2617	1.0742	.76019	
.24	.9607	.9718	.9886	.9705	.3874	—	.2.4956	.26141	.74	.6951	.7712	.9013	.6726	.2664	1.0681	.76958	
.25	.9575	.9694	.9877	.9682	.4189	—	.2.4027	.27217	.75	.6886	.7660	.8989	.6614	.2711	1.0624	.77694	
.26	.9541	.9670	.9867	.9656	.4515	—	.2.3173	.28291	.76	.6821	.7609	.8964	.6499	.2758	1.0570	.78225	
.27	.9506	.9645	.9856	.9629	.4851	—	.2.2385	.29364	.77	.6756	.7557	.8940	.6380	.2804	1.0519	.79753	
.28	.9470	.9619	.9846	.9600	.5197	—	.2.1656	.30435	.78	.6691	.7505	.8915	.6258	.2849	1.0471	.80677	
.29	.9433	.9592	.9835	.9570	.5553	—	.2.0979	.31504	.79	.6625	.7452	.8890	.6131	.2894	1.0425	.81397	
.30	.9395	.9564	.9823	.9539	.5919	—	.2.0351	.32572	.80	.6560	.7400	.8865	.6000	.2939	1.0382	.82511	
.31	.9355	.9535	.9811	.9507	.6293	—	.1.9765	.33637	.81	.6495	.7347	.8840	.5861	.2983	1.0342	.83426	
.32	.9315	.9506	.9799	.9474	.6677	—	.1.9219	.34701	.82	.6430	.7295	.8815	.5721	.3027	1.0305	.84335	
.33	.9274	.9476	.9787	.9440	.7069	—	.1.8707	.35762	.83	.6365	.7242	.8789	.5578	.3069	1.0270	.85239	
.34	.9231	.9445	.9774	.9404	.7470	—	.1.8229	.36822	.84	.6300	.7189	.8763	.5426	.3112	1.0237	.86140	
.35	.9188	.9413	.9761	.9367	.7879	—	.1.7780	.37879	.85	.6235	.7136	.8737	.5268	.3153	1.0207	.87037	
.36	.9143	.9380	.9747	.9330	.8295	—	.1.7358	.38935	.86	.6170	.7083	.8711	.5103	.3195	1.0179	.87929	
.37	.9098	.9347	.9733	.9290	.8719	—	.1.6961	.39988	.87	.6106	.7030	.8685	.4931	.3235	1.0153	.88518	
.38	.9052	.9313	.9719	.9250	.9149	—	.1.6587	.41039	.88	.6041	.6977	.8659	.4750	.3275	1.0129	.89703	
.39	.9004	.9278	.9705	.9208	.9587	—	.1.6234	.42087	.89	.5977	.6924	.8632	.4560	.3314	1.0108	.90583	
.40	.8956	.9233	.9690	.9165	.1003	—	.1.5901	.43133	.90	.5913	.6870	.8606	.4359	.3352	1.0089	.91460	
.41	.8907	.9207	.9675	.9121	.1048	—	.1.5587	.44177	.91	.5849	.6817	.8579	.4146	.3390	1.0071	.92322	
.42	.8857	.9170	.9659	.9075	.1094	—	.1.5289	.45215	.92	.5785	.6764	.8552	.3919	.3427	1.0056	.93201	
.43	.8807	.9132	.9643	.9028	.1140	—	.1.5007	.46257	.93	.5721	.6711	.8525	.3676	.3464	1.0043	.94065	
.44	.8755	.9094	.9627	.8980	.1187	—	.1.4740	.47293	.94	.5658	.6658	.8498	.3412	.3500	1.0031	.94925	
.45	.8703	.9055	.9611	.8930	.1234	—	.1.4487	.48326	.95	.5595	.6604	.8471	.3122	.3534	1.0022	.95781	
.46	.8650	.9016	.9584	.8879	.1281	—	.1.4246	.49357	.96	.5532	.6551	.8444	.2900	.3569	1.0014	.96633	
.47	.8596	.8976	.9577	.8827	.1329	—	.1.4018	.50385	.97	.5469	.6498	.8416	.2431	.3602	1.0008	.97481	
.48	.8541	.8935	.9560	.8773	.1378	—	.1.3801	.51410	.98	.5407	.6445	.8389	.1990	.3635	1.0003	.98325	
.49	.8486	.8894	.9542	.8717	.1426	—	.1.3595	.52433	.99	.5345	.6392	.8361	.1411	.3667	1.0001	.99165	
									1.00	.5233	.6339	.8333	.0000	.3695	1.0000	.1.0000	

TABLE II.—SUPERSONIC FLOW

 $\gamma = 7/5$ 

<i>M</i> or <i>M<sub>1</sub></i>	$\frac{p}{p_i}$	$\frac{\rho}{\rho_i}$	$\frac{T}{T_i}$	$\beta$	$\frac{q}{p_i}$	$\frac{A}{A_*}$	$\frac{U}{a_*}$	$\gamma$	$\mu$	<i>M<sub>2</sub></i>	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{\rho_{t2}}{\rho_{t1}}$
1.00	0.5243	0.6339	0.8333	0	0.3693	1.000	1.00000	0	0.0473	81.93	.9901	1.023	1.017	1.007	1.000
1.01	.5221	.6237	.8306	.1418	.3728	1.000	1.00831	.04473	.51	.9841	.9801	1.047	1.033	1.013	1.000
1.02	.5160	.6234	.8278	.2010	.3758	1.000	1.01658	.1257	.78.64	.9805	1.047	1.033	1.013	1.000	.5160
1.03	.5099	.6181	.8250	.2468	.3787	1.001	1.02481	.2294	.76.14	.9712	1.071	1.050	1.020	1.000	.5100
1.04	.5039	.6129	.8222	.2857	.3815	1.001	1.03300	.3510	.74.06	.9620	1.095	1.067	1.026	.9999	.5039
1.05	.4979	.6077	.8193	.3202	.3842	1.002	1.04114	.4874	.72.25	.9531	1.120	1.084	1.033	.9999	.4980
1.06	.4919	.6021	.8165	.3516	.3869	1.003	1.04925	.6367	.70.63	.9444	1.144	1.101	1.039	.9997	.4920
1.07	.4860	.5972	.8137	.3807	.3895	1.004	1.05731	.7973	.69.16	.9360	1.169	1.118	1.046	.9996	.4861
1.08	.4800	.5920	.8108	.4079	.3919	1.005	1.06533	.9580	.68.81	.9277	1.194	1.135	1.052	.9994	.4803
1.09	.4742	.5869	.8080	.4337	.3944	1.006	1.07331	1.148	.66.55	.9196	1.219	1.152	1.059	.9992	.4746
1.10	.4684	.5817	.8052	.4583	.3967	1.006	1.08124	1.336	.65.38	.9118	1.245	1.169	1.065	.9939	.4689
1.11	.4626	.5766	.8023	.4818	.3990	1.010	1.08913	1.532	.64.28	.9					

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TABLE II.—SUPERSONIC FLOW—Continued

γ = 7/5

<i>M</i> or <i>M</i> <sub>1</sub>	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{l'}{a_1}$	$\nu$	$\mu$	<i>M</i> <sub>2</sub>	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_{12}}{p_1}$	$\frac{p_1}{p_2}$
1.25	.3861	.5067	.7619	.7500	.4223	1.047	1.19523	4.830	52.13	.8126	1.656	1.429	1.159	.9871	.3911
1.26	.3809	.5019	.7590	.7666	.4233	1.050	1.20249	5.093	52.53	.8071	1.686	1.446	1.166	.9837	.3865
1.27	.3759	.4971	.7561	.7829	.4244	1.054	1.20972	5.359	51.94	.8016	1.715	1.463	1.172	.9842	.3819
1.28	.3708	.4923	.7532	.7990	.4253	1.058	1.21690	5.627	51.38	.7963	1.745	1.481	1.178	.9827	.3774
1.29	.3658	.4876	.7503	.8149	.4262	1.062	1.22404	5.898	50.82	.7911	1.775	1.498	1.185	.9811	.3729
1.30	.3609	.4829	.7474	.8307	.4270	1.066	1.23114	6.170	50.26	.7860	1.805	1.516	1.191	.9794	.3685
1.31	.3560	.4782	.7445	.8462	.4277	1.071	1.23819	6.445	49.76	.7809	1.835	1.533	1.197	.9776	.3642
1.32	.3512	.4736	.7416	.8616	.4283	1.075	1.24521	6.721	49.25	.7760	1.866	1.551	1.204	.9758	.3599
1.33	.3464	.4690	.7387	.8769	.4289	1.080	1.25218	7.000	48.75	.7712	1.897	1.568	1.210	.9738	.3557
1.34	.3417	.4644	.7358	.8920	.4294	1.084	1.25912	7.280	48.27	.7664	1.928	1.585	1.216	.9718	.3516
1.35	.3370	.4598	.7329	.9069	.4299	1.089	1.26601	7.561	47.79	.7618	1.960	1.603	1.223	.9697	.3475
1.36	.3323	.4553	.7300	.9217	.4303	1.094	1.27286	7.844	47.33	.7572	1.991	1.620	1.229	.9676	.3435
1.37	.3277	.4508	.7271	.9364	.4306	1.099	1.27968	8.128	46.88	.7527	2.023	1.636	1.235	.9653	.3395
1.38	.3232	.4463	.7242	.9510	.4308	1.104	1.28645	8.413	46.44	.7483	2.055	1.655	1.242	.9630	.3356
1.39	.3187	.4418	.7213	.9655	.4310	1.109	1.29318	8.699	46.01	.7440	2.087	1.672	1.248	.9607	.3317
1.40	.3142	.4374	.7184	.9798	.4311	1.115	1.29987	8.987	45.58	.7397	2.120	1.690	1.255	.9582	.3280
1.41	.3098	.4330	.7155	.9940	.4312	1.120	1.30652	9.276	45.17	.7355	2.153	1.707	1.261	.9557	.3242
1.42	.3055	.4287	.7126	1.008	.4312	1.126	1.31313	9.563	44.77	.7314	2.186	1.724	1.266	.9531	.3205
1.43	.3012	.4244	.7097	1.022	.4311	1.132	1.31970	9.855	44.37	.7274	2.219	1.742	1.274	.9504	.3169
1.44	.2969	.4201	.7069	1.036	.4310	1.138	1.32623	10.146	43.98	.7235	2.253	1.759	1.281	.9476	.3133
1.45	.2927	.4158	.7040	1.050	.4308	1.144	1.33272	10.438	43.60	.7196	2.286	1.776	1.287	.9448	.3098
1.46	.2886	.4116	.7011	1.064	.4306	1.150	1.33917	10.731	43.23	.7157	2.320	1.783	1.294	.9420	.3063
1.47	.2845	.4074	.6982	1.077	.4303	1.156	1.34558	11.023	42.86	.7120	2.354	1.811	1.300	.9390	.3029
1.48	.2804	.4032	.6954	1.091	.4299	1.163	1.35195	11.317	42.51	.7083	2.389	1.828	1.307	.9360	.2996
1.49	.2764	.3991	.6925	1.105	.4295	1.169	1.35828	11.611	42.16	.7047	2.423	1.845	1.314	.9329	.2962
1.50	.2724	.3950	.6897	1.118	.4290	1.176	1.36458	11.905	41.81	.7011	2.458	1.862	1.320	.9298	.2930
1.51	.2685	.3909	.6868	1.131	.4285	1.183	1.37083	12.200	41.47	.6976	2.493	1.879	1.327	.9266	.2898
1.52	.2646	.3869	.6840	1.145	.4279	1.190	1.37705	12.495	41.14	.6941	2.529	1.896	1.334	.9233	.2866
1.53	.2608	.3829	.6811	1.158	.4273	1.197	1.38322	12.790	40.81	.6907	2.564	1.913	1.340	.9200	.2835
1.54	.2570	.3789	.6783	1.171	.4266	1.204	1.38936	13.086	40.49	.6874	2.600	1.930	1.347	.9166	.2804
1.55	.2533	.3750	.6754	1.184	.4259	1.212	1.39546	13.381	40.18	.6841	2.636	1.947	1.354	.9132	.2773
1.56	.2496	.3710	.6726	1.197	.4252	1.219	1.40152	13.677	39.87	.6809	2.673	1.964	1.361	.9097	.2744
1.57	.2459	.3672	.6698	1.210	.4243	1.227	1.40755	13.973	39.56	.6777	2.709	1.981	1.367	.9061	.2714
1.58	.2423	.3633	.6670	1.223	.4235	1.234	1.41353	14.269	39.27	.6746	2.746	1.998	1.374	.9026	.2685
1.59	.2388	.3595	.6642	1.236	.4226	1.242	1.41948	14.564	38.97	.6715	2.783	2.015	1.381	.8989	.2656
1.60	.2353	.3557	.6614	1.249	.4216	1.250	1.42539	14.861	38.68	.6684	2.820	2.032	1.388	.8952	.2628
1.61	.2318	.3520	.6586	1.262	.4206	1.258	1.43127	15.156	38.40	.6655	2.857	2.049	1.395	.8915	.2600
1.62	.2294	.3483	.6558	1.275	.4196	1.267	1.43710	15.452	38.12	.6625	2.895	2.065	1.402	.8857	.2573
1.63	.2250	.3446	.6530	1.287	.4185	1.275	1.44290	15.747	37.84	.6596	2.933	2.082	1.409	.8838	.2546
1.64	.2217	.3409	.6502	1.300	.4174	1.284	1.44866	16.043	37.57	.6568	2.971	2.099	1.416	.8799	.2519
1.65	.2184	.3373	.6475	1.312	.4162	1.292	1.45439	16.338	37.31	.6540	3.010	2.115	1.423	.8760	.2493
1.66	.2151	.3337	.6447	1.325	.4150	1.301	1.46008	16.633	37.04	.6512	3.048	2.132	1.430	.8720	.2467
1.67	.2119	.3302	.6419	1.337	.4138	1.310	1.46573	16.928	36.78	.6485	3.087	2.148	1.437	.8680	.2442
1.68	.2088	.3266	.6392	1.350	.4125	1.319	1.47135	17.222	36.53	.6458	3.126	2.165	1.444	.8640	.2417
1.69	.2057	.3232	.6364	1.362	.4112	1.328	1.47693	17.516	36.28	.6431	3.165	2.181	1.451	.8598	.2392
1.70	.2026	.3197	.6337	1.375	.4098	1.338	1.48247	17.810	36.03	.6405	3.205	2.198	1.458	.8557	.2368
1.71	.1996	.3163	.6310	1.387	.4085	1.347	1.48798	18.103	35.79	.6380	3.245	2.214	1.466	.8516	.2344
1.72	.1966	.3129	.6283	1.399	.4071	1.357	1.49345	18.397	35.55	.6355	3.285	2.230	1.473	.8474	.2320
1.73	.1936	.3095	.6256	1.412	.4056	1.367	1.49889	18.689	35.31	.6330	3.325	2.247	1.480	.8431	.2296
1.74	.1907	.3062	.6229	1.424	.4041	1.376	1.50429	18.981	35.08	.6305	3.366	2.263	1.487	.8389	.2273
1.75	.1878	.3029	.6202	1.436	.4026	1.386	1.50966	19.273	34.85	.6281	3.406	2.279	1.495	.8346	.2251
1.76	.1850	.2996	.6175	1.448	.4011	1.397	1.51499	19.565	34.62	.6257	3.447	2.295	1.502	.8302	.2224
1.77	.1822	.2964	.6148	1.460	.3996	1.407	1.52029	19.855	34.40	.6234	3.488	2.311	1.509	.8259	.2206
1.78	.1794	.2931	.6121	1.473	.3980	1.418	1.52535	20.146	34.18	.6210	3.530	2.327	1.517	.8215	.2184
1.79	.1767	.2900	.6095	1.485	.3964	1.428	1.53078	20.436	33.96	.6188	3.571	2.343	1.524	.8171	.2163
1.80	.1740	.2868	.6068	1.497	.3947	1.439	1.53598	20.725	33.75	.6165	3.613	2.359	1.532	.8127	.2142
1.81	.1714	.2837	.6041	1.509	.3931	1.450	1.54114	21.014	33.54	.6143	3.655	2.375	1.539	.8082	.2121
1.82	.1688	.2806	.6015	1.521	.3914	1.461	1.54626	21.302	33.33	.6121	3.698	2.391	1.547	.8038	.2100
1.83	.1662	.2776	.5989	1.533	.3897	1.472	1.55136	21.590	33.12	.6099	3.740	2.407	1.554	.7993	.2080
1.84	.1637	.2745	.5963	1.545	.3879	1.484	1.55642	21.877	32.92	.6078	3.783	2.422	1.562	.7948	.2060
1.85	.1612	.2715	.5936	1.556	.3862	1.495	1.56145	22.163	32.72	.6057	3.826	2.438	1.569	.7902	.2040
1.86	.1587	.2686	.5910	1.568	.3844	1.507	1.56644	22.449	32.52	.6036	3.870	2.454	1.577	.7857	.2020
1.87	.1563	.2656	.5884	1.580	.3826	1.519	1.57140	22.735	32.33	.6016	3.913	2.469	1.585	.7811	.2001
1.88	.1539	.2627	.5859	1.592	.3808	1.531	1.57633	23.019	32.13	.5996	3.957	2.485	1.592	.7765	.1982
1.89	.1516	.2598	.5833	1.604	.3790	1.543	1.58123	23.303	31.94	.5976	4.001	2.500	1.600	.7720	.1963
1.90	.1492	.2570	.5807	1.616	.3771	1.555	1.58609	23.586	31.76	.5956	4.045	2.516	1.608	.7674	.1945
1.91	.1470	.2542	.578												

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{V}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t_2}}{p_{t_1}}$	$\frac{p_1}{p_{t_2}}$	
2.15	.1011	-	.1946	.5196	1.903	.3272	1.919	1.69774	30.425	27.72	.5540	5.226	2.882	1.813	.6511	.1553
2.16	.0956	-	.1925	.5173	1.915	.3252	1.935	1.70183	30.689	27.58	.5525	5.277	2.896	1.822	.6464	.1540
2.17	.9802	-	.1903	.5150	1.926	.3231	1.953	1.70589	30.951	27.44	.5511	5.327	2.910	1.831	.6419	.1527
2.18	.9649	-	.1882	.5127	1.937	.3210	1.970	1.70992	31.212	27.30	.5498	5.378	2.924	1.839	.6373	.1514
2.19	.9500	-	.1861	.5104	1.948	.3189	1.987	1.71393	31.473	27.17	.5484	5.429	2.938	1.848	.6327	.1502
2.20	.9352	-	.1841	.5081	1.960	.3169	2.005	1.71791	31.732	27.04	.5471	5.480	2.951	1.857	.6281	.1489
2.21	.9207	-	.1820	.5059	1.971	.3148	2.023	1.72187	31.991	26.90	.5457	5.531	2.965	1.866	.6236	.1476
2.22	.9064	-	.1800	.5036	1.982	.3127	2.041	1.72579	32.250	26.77	.5444	5.583	2.976	1.875	.6191	.1464
2.23	.8923	-	.1780	.5014	1.993	.3106	2.059	1.72970	32.507	26.64	.5431	5.636	2.992	1.883	.6145	.1452
2.24	.8785	-	.1760	.4991	2.004	.3085	2.078	1.73357	32.763	26.51	.5418	5.687	3.005	1.892	.6100	.1440
2.25	.8648	-	.1740	.4969	2.016	.3065	2.096	1.73742	33.018	26.39	.5406	5.740	3.019	1.901	.6055	.1428
2.26	.8514	-	.1721	.4947	2.027	.3044	2.115	1.74125	33.273	26.26	.5393	5.792	3.032	1.910	.6011	.1417
2.27	.8382	-	.1702	.4925	2.038	.3023	2.134	1.74504	33.527	26.14	.5381	5.845	3.045	1.919	.5966	.1405
2.28	.8251	-	.1683	.4903	2.049	.3003	2.154	1.74882	33.780	26.01	.5368	5.898	3.058	1.929	.5921	.1394
2.29	.8123	-	.1664	.4881	2.060	.2982	2.173	1.75257	34.032	25.89	.5356	5.951	3.071	1.938	.5877	.1382
2.30	.7997	-	.1646	.4859	2.071	.2961	2.193	1.75629	34.283	25.77	.5344	6.005	3.085	1.947	.5833	.1371
2.31	.7873	-	.1628	.4837	2.082	.2941	2.213	1.75999	34.533	25.65	.5332	6.059	3.098	1.956	.5789	.1360
2.32	.7751	-	.1609	.4816	2.093	.2920	2.233	1.76366	34.783	25.53	.5321	6.113	3.110	1.965	.5745	.1349
2.33	.7631	-	.1592	.4794	2.104	.2900	2.254	1.76731	35.031	25.42	.5309	6.167	3.123	1.974	.5702	.1338
2.34	.7512	-	.1574	.4773	2.116	.2879	2.274	1.77093	35.279	25.30	.5297	6.222	3.136	1.984	.5658	.1326
2.35	.7396	-	.1556	.4752	2.127	.2859	2.295	1.77453	35.526	25.18	.5286	6.276	3.149	1.993	.5615	.1317
2.36	.7281	-	.1539	.4731	2.138	.2839	2.316	1.77811	35.771	25.07	.5275	6.331	3.162	2.002	.5572	.1307
2.37	.7168	-	.1522	.4709	2.149	.2818	2.334	1.78166	36.017	24.96	.5264	6.386	3.174	2.012	.5529	.1297
2.38	.7057	-	.1505	.4688	2.160	.2798	2.359	1.78519	36.261	24.85	.5253	6.442	3.187	2.021	.5486	.1286
2.39	.6948	-	.1488	.4668	2.171	.2778	2.381	1.78869	36.504	24.73	.5242	6.497	3.199	2.031	.5444	.1276
2.40	.6840	-	.1472	.4647	2.182	.2758	2.403	1.79218	36.746	24.62	.5231	6.553	3.212	2.040	.5401	.1266
2.41	.6734	-	.1456	.4626	2.193	.2738	2.425	1.79563	36.988	24.52	.5221	6.609	3.224	2.050	.5359	.1257
2.42	.6630	-	.1439	.4606	2.204	.2718	2.448	1.79907	37.229	24.41	.5210	6.666	3.237	2.059	.5317	.1247
2.43	.6527	-	.1424	.4585	2.215	.2698	2.471	1.80248	37.469	24.30	.5200	6.722	3.249	2.069	.5276	.1237
2.44	.6426	-	.1408	.4565	2.226	.2678	2.494	1.80587	37.708	24.19	.5189	6.779	3.261	2.079	.5234	.1228
2.45	.6327	-	.1392	.4544	2.237	.2658	2.517	1.80924	37.946	24.09	.5179	6.836	3.273	2.088	.5193	.1218
2.46	.6229	-	.1377	.4524	2.248	.2639	2.540	1.81258	38.183	23.99	.5169	6.894	3.285	2.098	.5152	.1209
2.47	.6133	-	.1362	.4504	2.259	.2619	2.564	1.81591	38.420	23.88	.5159	6.951	3.295	2.105	.5111	.1200
2.48	.6035	-	.1346	.4484	2.270	.2599	2.588	1.81921	38.655	23.78	.5149	7.009	3.310	2.118	.5071	.1191
2.49	.5945	-	.1332	.4464	2.280	.2580	2.612	1.82249	38.890	23.68	.5140	7.067	3.321	2.128	.5030	.1182
2.50	.5853	-	.1317	.4444	2.291	.2561	2.637	1.82574	39.124	23.58	.5130	7.125	3.333	2.138	.4990	.1173
2.51	.5762	-	.1302	.4425	2.302	.2541	2.661	1.82908	39.357	23.48	.5120	7.183	3.345	2.147	.4950	.1164
2.52	.5674	-	.1285	.4405	2.313	.2522	2.686	1.83219	39.589	23.38	.5111	7.242	3.357	2.157	.4911	.1155
2.53	.5586	-	.1274	.4386	2.324	.2503	2.712	1.83538	39.820	23.28	.5102	7.301	3.369	2.167	.4871	.1147
2.54	.5500	-	.1260	.4366	2.335	.2484	2.737	1.83855	40.050	23.18	.5092	7.360	3.380	2.177	.4832	.1138
2.55	.5415	-	.1246	.4347	2.346	.2465	2.763	1.84170	40.280	23.09	.5083	7.420	3.392	2.187	.4793	.1130
2.56	.5332	-	.1232	.4328	2.357	.2446	2.789	1.84483	40.509	22.99	.5074	7.479	3.403	2.198	.4754	.1122
2.57	.5250	-	.1218	.4309	2.367	.2427	2.815	1.84794	40.736	22.91	.5065	7.539	3.415	2.208	.4715	.1113
2.58	.5169	-	.1205	.4289	2.378	.2409	2.842	1.85103	40.963	22.81	.5056	7.599	3.426	2.218	.4677	.1105
2.59	.5090	-	.1192	.4271	2.389	.2390	2.869	1.85410	41.189	22.71	.5047	7.659	3.438	2.228	.4639	.1097
2.60	.5011	-	.1179	.4252	2.400	.2371	2.896	1.85714	41.415	22.62	.5039	7.720	3.449	2.238	.4601	.1080
2.61	.4935	-	.1166	.4233	2.411	.2353	2.923	1.86017	41.639	22.53	.5030	7.781	3.460	2.249	.4564	.1081
2.62	.4859	-	.1153	.4214	2.422	.2335	2.951	1.86318	41.863	22.44	.5022	7.842	3.471	2.259	.4526	.1074
2.63	.4784	-	.1140	.4196	2.432	.2317	2.979	1.86616	42.086	22.35	.5013	7.903	3.483	2.269	.4489	.1066
2.64	.4711	-	.1128	.4177	2.443	.2300	3.007	1.86913	42.307	22.26	.5005	7.965	3.494	2.280	.4452	.1058
2.65	.4639	-	.1115	.4159	2.454	.2280	3.036	1.87208	42.529	22.17	.4996	8.026	3.505	2.290	.4416	.1051
2.66	.4565	-	.1103	.4141	2.465	.2262	3.065	1.87501	42.749	22.09	.4988	8.086	3.516	2.301	.4379	.1043
2.67	.4496	-	.1091	.4122	2.476	.2245	3.094	1.87792	42.968	22.00	.4980	8.150	3.527	2.311	.4343	.1036
2.68	.4429	-	.1079	.4104	2.486	.2227	3.123	1.88081	43.187	21.91	.4972	8.213	3.537	2.322	.4307	.1028
2.69	.4362	-	.1067	.4086	2.497	.2209	3.153	1.88368	43.405	21.82	.4964	8.275	3.548	2.332	.4271	.1021
2.70	.4295	-	.1056	.4068	2.508	.2192	3.183	1.88653	43.621	21.74	.4956	8.338	3.559	2.343	.4236	.1014
2.71	.4229	-	.1044	.4051	2.519	.2174	3.213	1.88936	43.838	21.65	.4949	8.401	3.570	2.354	.4201	.1007
2.72	.4165	-	.1033	.4033	2.530	.2157	3.244	1.89218	44.053	21.57	.4941	8.465	3.580	2.364	.4166	.1006
2.73	.4102	-	.1022	.4015	2.540	.2140	3.275	1.89497	44.267	21.49	.4933	8.528	3.591	2.375	.4131	.9929
2.74	.4039	-	.1010	.3996	2.551	.2124	3.306	1.89775	44.481	21.41	.4926	8.592	3.601	2.386	.4097	.9860
2.75	.3978	-	.9944	.3980	2.562	.2106	3.338	1.90051	44.694	20.32	.4918	8.656	3.612	2.397	.4062	.9792
2.76	.3917	-	.9885	.3963	2.572	.2089	3.370	1.90325	44.906	20.24	.4911	8.721	3.622	2.407	.4028	.9721
2.77	.3858	-	.9778	.3945	2.583	.2072	3.402	1.90598	45.117	20.16	.4903	8.785	3.633	2.418	.3994	.9658
2.78	.3799	-	.9671	.3928	2.594	.2055	3.434	1.90868	45.327	20.08	.4896	8.850	3.643	2.429	.3961	.9591

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7.5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{U}{a_1}$	$\nu$	$\mu$	$M_1$	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_1}{p_2}$	$\frac{p_1}{p_2}$	
3.05	.2526	-1	.7226	-1	.3496	2.881	1.645	4.441	1.9764	50.713	19.14	.4723	10.69	3.902	2.738	.3145
3.06	.2489	-1	.7149	-1	.3481	2.892	1.631	4.483	1.9777	50.902	19.07	.4717	10.76	3.911	2.750	.3118
3.07	.2452	-1	.7074	-1	.3466	2.903	1.618	4.526	1.9799	51.090	19.01	.4712	10.83	3.920	2.762	.3091
3.08	.2416	-1	.6999	-1	.3452	2.913	1.604	4.570	1.9821	51.277	18.95	.4706	10.90	3.929	2.774	.3065
3.09	.2380	-1	.6925	-1	.3437	2.924	1.591	4.613	1.9844	51.464	18.88	.4701	10.97	3.938	2.786	.3038
3.10	.2345	-1	.6852	-1	.3422	2.934	1.577	4.657	1.9866	51.650	18.82	.4695	11.05	3.947	2.799	.3012
3.11	.2310	-1	.6779	-1	.3405	2.945	1.564	4.702	1.9887	51.835	18.76	.4690	11.12	3.955	2.811	.2986
3.12	.2276	-1	.6708	-1	.3393	2.955	1.551	4.747	1.9907	52.020	18.69	.4685	11.19	3.964	2.823	.2960
3.13	.2243	-1	.6637	-1	.3379	2.966	1.538	4.792	1.9931	52.203	18.63	.4679	11.26	3.973	2.835	.2935
3.14	.2210	-1	.6568	-1	.3365	2.977	1.525	4.838	1.9952	52.386	18.57	.4674	11.34	3.981	2.848	.2910
3.15	.2177	-1	.6499	-1	.3351	2.987	1.512	4.884	1.9974	52.569	18.51	.4669	11.41	3.990	2.860	.2885
3.16	.2146	-1	.6430	-1	.3337	2.996	1.500	4.930	1.9992	52.751	18.45	.4664	11.48	3.998	2.872	.2860
3.17	.2114	-1	.6363	-1	.3323	3.008	1.487	4.977	2.0016	52.931	18.39	.4659	11.56	4.006	2.885	.2835
3.18	.2083	-1	.6296	-1	.3309	3.019	1.475	5.025	2.0037	53.112	18.33	.4654	11.63	4.015	2.897	.2811
3.19	.2053	-1	.6231	-1	.3295	3.029	1.462	5.073	2.0057	53.292	18.27	.4648	11.71	4.023	2.909	.2786
3.20	.2023	-1	.6165	-1	.3281	3.040	1.450	5.121	2.0078	53.470	18.21	.4643	11.78	4.031	2.922	.2762
3.21	.1993	-1	.6101	-1	.3267	3.050	1.438	5.167	2.0091	53.648	18.15	.4639	11.85	4.040	2.935	.2738
3.22	.1964	-1	.6037	-1	.3253	3.061	1.426	5.219	2.0119	53.826	18.09	.4634	11.93	4.048	2.947	.2715
3.23	.1936	-1	.5975	-1	.3240	3.071	1.414	5.268	2.0138	54.003	18.03	.4629	12.01	4.056	2.960	.2691
3.24	.1908	-1	.5912	-1	.3226	3.082	1.402	5.319	2.0159	54.179	17.98	.4624	12.08	4.064	2.972	.2664
3.25	.1880	-1	.5851	-1	.3213	3.092	1.390	5.369	2.0179	54.355	17.92	.4619	12.16	4.072	2.985	.2645
3.26	.1853	-1	.5790	-1	.3199	3.103	1.378	5.420	2.0198	54.529	17.86	.4614	12.23	4.080	2.998	.2622
3.27	.1826	-1	.5730	-1	.3186	3.113	1.367	5.472	2.0216	54.703	17.81	.4610	12.31	4.088	3.011	.2600
3.28	.1799	-1	.5671	-1	.3173	3.124	1.355	5.523	2.0232	54.877	17.75	.4605	12.38	4.096	3.023	.2577
3.29	.1773	-1	.5612	-1	.3160	3.134	1.344	5.576	2.0258	55.050	17.70	.4600	12.46	4.104	3.036	.2555
3.30	.1748	-1	.5554	-1	.3147	3.145	1.332	5.629	2.0281	55.222	17.64	.4596	12.54	4.112	3.049	.2533
3.31	.1722	-1	.5497	-1	.3134	3.155	1.321	5.682	2.0294	55.393	17.58	.4591	12.62	4.120	3.062	.2511
3.32	.1698	-1	.5440	-1	.3121	3.166	1.310	5.736	2.0316	55.564	17.53	.4587	12.69	4.128	3.075	.2489
3.33	.1673	-1	.5384	-1	.3105	3.176	1.309	5.790	2.0335	55.734	17.48	.4582	12.77	4.135	3.088	.2468
3.34	.1649	-1	.5329	-1	.3095	3.187	1.288	5.845	2.0354	55.904	17.42	.4578	12.85	4.143	3.101	.2446
3.35	.1625	-1	.5274	-1	.3082	3.197	1.277	5.900	2.0373	56.073	17.37	.4573	12.93	4.151	3.114	.2425
3.36	.1602	-1	.5220	-1	.3069	3.208	1.266	5.956	2.0392	56.241	17.31	.4569	13.00	4.158	3.127	.2404
3.37	.1579	-1	.5166	-1	.3057	3.218	1.255	6.012	2.0410	56.409	17.26	.4565	13.08	4.166	3.141	.2383
3.38	.1557	-1	.5113	-1	.3044	3.229	1.245	6.069	2.0429	56.576	17.21	.4560	13.16	4.173	3.154	.2363
3.39	.1534	-1	.5061	-1	.3032	3.239	1.234	6.126	2.0447	56.742	17.16	.4556	13.24	4.181	3.167	.2342
3.40	.1512	-1	.5009	-1	.3019	3.250	1.224	6.184	2.0465	56.907	17.10	.4552	13.32	4.188	3.180	.2322
3.41	.1491	-1	.4958	-1	.3007	3.260	1.214	6.242	2.0483	57.073	17.05	.4548	13.40	4.196	3.194	.2302
3.42	.1470	-1	.4908	-1	.2995	3.271	1.203	6.301	2.0501	57.237	17.00	.4544	13.48	4.203	3.207	.2282
3.43	.1449	-1	.4858	-1	.2982	3.281	1.193	6.360	2.0519	57.401	16.95	.4540	13.56	4.211	3.220	.2263
3.44	.1428	-1	.4805	-1	.2970	3.291	1.183	6.420	2.0537	57.564	16.90	.4535	13.64	4.218	3.234	.2243
3.45	.1405	-1	.4759	-1	.2958	3.302	1.173	6.480	2.0551	57.726	16.85	.4531	13.72	4.225	3.247	.2224
3.46	.1388	-1	.4711	-1	.2946	3.312	1.163	6.541	2.0572	57.884	16.80	.4527	13.80	4.232	3.261	.2205
3.47	.1366	-1	.4663	-1	.2934	3.323	1.153	6.602	2.0590	58.050	16.75	.4523	13.88	4.240	3.274	.2186
3.48	.1349	-1	.4616	-1	.2922	3.333	1.144	6.664	2.0605	58.210	16.70	.4519	13.96	4.247	3.288	.2167
3.49	.1330	-1	.4569	-1	.2910	3.344	1.134	6.727	2.0624	58.370	16.65	.4515	14.04	4.254	3.301	.2148
3.50	.1311	-1	.4523	-1	.2899	3.354	1.124	6.790	2.0641	58.530	16.60	.4512	14.13	4.261	3.315	.2129
3.51	.1293	-1	.4478	-1	.2887	3.365	1.115	6.853	2.0659	58.689	16.55	.4508	14.21	4.268	3.329	.2111
3.52	.1274	-1	.4433	-1	.2875	3.375	1.105	6.917	2.0679	58.847	16.51	.4504	14.29	4.275	3.343	.2093
3.53	.1256	-1	.4388	-1	.2864	3.385	1.096	6.982	2.0692	59.004	16.46	.4500	14.37	4.282	3.356	.2075
3.54	.1239	-1	.4344	-1	.2852	3.396	1.087	7.047	2.0704	59.162	16.41	.4496	14.45	4.289	3.370	.2057
3.55	.1221	-1	.4300	-1	.2841	3.406	1.078	7.113	2.0726	59.318	16.36	.4492	14.54	4.296	3.384	.2039
3.56	.1204	-1	.4257	-1	.2829	3.417	1.069	7.179	2.0742	59.474	16.31	.4489	14.62	4.303	3.398	.2022
3.57	.1188	-1	.4214	-1	.2818	3.427	1.059	7.246	2.0759	59.629	16.27	.4485	14.70	4.309	3.412	.2004
3.58	.1171	-1	.4172	-1	.2806	3.437	1.051	7.313	2.0774	59.784	16.22	.4481	14.79	4.316	3.426	.1987
3.59	.1155	-1	.4131	-1	.2795	3.448	1.042	7.382	2.07916	59.938	16.17	.4478	14.87	4.323	3.440	.1970
3.60	.1138	-1	.4089	-1	.2784	3.458	1.033	7.450	2.08077	60.091	16.13	.4474	14.95	4.330	3.454	.1953
3.61	.1123	-1	.4049	-1	.2773	3.469	1.024	7.519	2.08238	60.244	16.08	.4471	15.04	4.336	3.468	.1936
3.62	.1107	-1	.4005	-1	.2762	3.479	1.016	7.589	2.08397	60.397	16.04	.4467	15.12	4.343	3.482	.1920
3.63	.1092	-1	.3966	-1	.2751	3.490	1.007	7.659	2.08556	60.549	15.99	.4463	15.21	4.350	3.496	.1903
3.64	.1076	-1	.3929	-1	.2740	3.500	.9984	7.730	2.08713	60.700	15.95	.4460	15.29	4.356	3.510	.1887
3.65	.1062	-1	.3890	-1	.2729	3.510	.9900	7.802	2.08870	60.851	15.90	.4456	15.38	4.363	3.525	.1871
3.66	.1047	-1	.3852	-1	.2718	3.521	.9817	7.874	2.09026	61.000	15.86	.4453	15.46	4.369	3.539	.1855
3.67	.1032	-1	.3813	-1	.2707	3.531	.9734	7.947	2.09180	61.150	15.81	.4450	15.55	4.376	3.553	.1839
3.68	.1018	-1	.3776	-1	.2697	3.542	.9652	8.020	2.09334	61.299	15.77	.4446	15.63	4.382	3.568	.1823
3.69	.1004	-1	.3739	-1	.2686	3.552	.9570	8.084	2.09487	61.447	15.72	.4443	15.72			

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 1.75$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{U}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t_2}}{p_{t_1}}$	$\frac{p_1}{p_2}$			
3.95	.7042	-1	.2902	-1	.2427	3.821	.7681	-1	10.25	2.13163	65.118	14.67	.4363	18.04	4.544	.3969	.1448	.4805
3.96	.6948	-1	.2874	-1	.2418	3.832	.7627	-1	10.34	2.13294	65.253	14.63	.4360	18.13	4.549	.3985	.1435	.4841
3.97	.6855	-1	.2846	-1	.2408	3.842	.7563	-1	10.44	2.13424	65.386	14.59	.4358	18.22	4.555	.4000	.1423	.4817
3.98	.6764	-1	.2819	-1	.2399	3.852	.7500	-1	10.53	2.13553	65.520	14.55	.4355	18.31	4.560	.4016	.1411	.4793
3.99	.6675	-1	.2793	-1	.2380	3.863	.7438	-1	10.62	2.13681	65.652	14.52	.4352	18.41	4.566	.4031	.1399	.4770
4.00	.6586	-2	.2766	-1	.2381	3.873	.7376	-1	10.72	2.13809	65.785	14.48	.4350	18.50	4.571	.4047	.1388	.4747
4.01	.6499	-1	.2740	-1	.2372	3.883	.7315	-1	10.81	2.13936	65.917	14.44	.4347	18.59	4.577	.4062	.1376	.4723
4.02	.6413	-1	.2714	-1	.2363	3.894	.7255	-1	10.91	2.14062	66.048	14.40	.4344	18.69	4.582	.4078	.1364	.4700
4.03	.6228	-2	.2688	-1	.2354	3.904	.7194	-1	11.01	2.14185	66.179	14.37	.4342	18.78	4.588	.4094	.1353	.4678
4.04	.6245	-2	.2663	-1	.2345	3.914	.7135	-1	11.11	2.14312	66.309	14.33	.4339	18.88	4.593	.4110	.1342	.4655
4.05	.6163	2	.2638	-1	.2336	3.925	.7076	-1	11.21	2.14436	66.439	14.30	.4336	18.97	4.598	.4125	.1330	.4633
4.06	.6082	-2	.2613	-1	.2327	3.935	.7017	-1	11.31	2.14560	66.569	14.26	.4334	19.06	4.604	.4141	.1319	.4610
4.07	.6002	-2	.2589	-1	.2319	3.945	.6959	-1	11.41	2.14682	66.694	14.22	.4331	19.16	4.609	.4157	.1308	.4588
4.08	.5923	-2	.2564	-1	.2310	3.956	.6902	-1	11.51	2.14804	66.826	14.19	.4329	19.25	4.614	.4173	.1297	.4566
4.09	.5845	-1	.2540	-1	.2301	3.966	.6845	-1	11.61	2.14926	66.954	14.15	.4326	19.35	4.619	.4189	.1286	.4544
4.10	.5769	-2	.2516	-1	.2293	3.976	.6788	-1	11.71	2.15046	67.082	14.12	.4324	19.45	4.624	.4205	.1276	.4523
4.11	.5694	-1	.2493	-1	.2284	3.986	.6732	-1	11.82	2.15166	67.209	14.08	.4321	19.54	4.630	.4221	.1265	.4501
4.12	.5619	-1	.2470	-1	.2275	3.997	.6677	-1	11.92	2.15285	67.336	14.05	.4319	19.64	4.635	.4237	.1254	.4480
4.13	.5546	-2	.2447	-1	.2267	4.007	.6622	-1	12.03	2.15404	67.462	14.01	.4316	19.73	4.640	.4253	.1244	.4459
4.14	.5474	-1	.2424	-1	.2258	4.017	.6568	-1	12.14	2.15522	67.588	13.98	.4314	19.83	4.645	.4269	.1234	.4438
4.15	.5403	-2	.2401	-1	.2250	4.028	.6514	-1	12.24	2.15639	67.713	13.94	.4311	19.93	4.650	.4285	.1223	.4417
4.16	.5333	-1	.2379	-1	.2242	4.038	.6460	-1	12.35	2.15756	67.84	13.91	.4309	20.02	4.655	.4301	.1213	.4396
4.17	.5264	-2	.2357	-1	.2233	4.048	.6407	-1	12.46	2.15871	67.963	13.88	.4306	20.12	4.660	.4318	.1203	.4375
4.18	.5193	-2	.2335	-1	.2225	4.059	.6354	-1	12.57	2.15987	68.07	13.84	.4304	20.22	4.665	.4334	.1193	.4355
4.19	.5128	-2	.2313	-1	.2217	4.069	.6302	-1	12.68	2.16101	68.210	13.81	.4302	20.32	4.670	.4350	.1183	.4334
4.20	.5062	-2	.2292	-1	.2208	4.079	.6251	-1	12.79	2.16215	68.333	13.77	.4299	20.41	4.675	.4367	.1173	.4314
4.21	.4987	-2	.2271	-1	.2200	4.090	.6200	-1	12.90	2.16329	68.456	13.74	.4297	20.51	4.680	.4383	.1164	.4294
4.22	.4932	-2	.2250	-1	.2192	4.100	.6149	-1	13.02	2.16442	68.578	13.71	.4295	20.61	4.685	.4399	.1154	.4274
4.23	.4869	-2	.2229	-1	.2184	4.110	.6096	-1	13.13	2.16554	68.700	13.67	.4292	20.71	4.690	.4416	.1144	.4255
4.24	.4806	-2	.2209	-1	.2176	4.120	.6049	-1	13.25	2.16665	68.821	13.64	.4290	20.81	4.694	.4432	.1135	.4235
4.25	.4745	-2	.2189	-1	.2168	4.131	.5939	-1	13.36	2.16776	68.942	13.61	.4288	20.91	4.699	.4449	.1126	.4215
4.26	.4684	-2	.2169	-1	.2160	4.141	.5894	-1	13.48	2.16886	69.053	13.58	.4286	21.01	4.704	.4466	.1116	.4196
4.27	.4624	-2	.2149	-1	.2152	4.151	.5802	-1	13.60	2.16996	69.183	13.54	.4283	21.11	4.709	.4482	.1107	.4177
4.28	.4565	-2	.2129	-1	.2144	4.162	.5854	-1	13.72	2.17105	69.302	13.51	.4281	21.20	4.713	.4499	.1098	.4158
4.29	.4507	-2	.2110	-1	.2136	4.172	.5806	-1	13.83	2.17214	69.422	13.46	.4279	21.30	4.718	.4516	.1089	.4139
4.30	.4449	-2	.2090	-1	.2129	4.182	.5759	-1	13.95	2.17321	69.541	13.45	.4277	21.41	4.723	.4532	.1080	.4120
4.31	.4393	-1	.2071	-1	.2121	4.192	.5712	-1	14.08	2.17429	69.659	13.42	.4275	21.51	4.728	.4549	.1071	.4101
4.32	.4337	-2	.2052	-1	.2113	4.203	.5666	-1	14.20	2.17535	69.777	13.38	.4272	21.61	4.732	.4566	.1062	.4082
4.33	.4284	-2	.2034	-1	.2105	4.213	.5620	-1	14.32	2.17642	69.895	13.35	.4270	21.71	4.737	.4583	.1054	.4061
4.34	.4226	-2	.2015	-1	.2098	4.223	.5574	-1	14.45	2.17747	70.012	13.32	.4268	21.81	4.741	.4600	.1045	.4046
4.35	.4174	-2	.1997	-1	.2090	4.233	.5529	-1	14.57	2.17852	70.128	13.29	.4266	21.91	4.746	.4617	.1036	.4027
4.36	.4121	-2	.1979	-1	.2083	4.244	.5484	-1	14.70	2.17956	70.245	13.26	.4264	22.01	4.751	.4633	.1028	.4009
4.37	.4069	-2	.1961	-1	.2075	4.254	.5440	-1	14.82	2.18060	70.361	13.23	.4262	22.11	4.755	.4651	.1020	.3991
4.38	.4018	-2	.1944	-1	.2067	4.264	.5396	-1	14.95	2.18163	70.476	13.20	.4260	22.22	4.760	.4668	.1011	.3973
4.39	.3966	-1	.1926	-1	.2060	4.275	.5352	-1	15.08	2.18266	70.591	13.17	.4258	22.32	4.764	.4685	.1003	.3956
4.40	.3918	-2	.1909	-1	.2053	4.285	.5309	-1	15.21	2.18368	70.706	13.14	.4255	22.42	4.768	.4702	.9845	.3938
4.41	.3866	-2	.1892	-1	.2045	4.295	.5266	-1	15.34	2.18470	70.820	13.11	.4253	22.52	4.773	.4719	.9807	.3921
4.42	.3820	-2	.1875	-1	.2038	4.305	.5224	-1	15.47	2.18571	70.934	13.08	.4251	22.63	4.777	.4736	.9787	.3903
4.43	.3772	-2	.1858	-1	.2030	4.316	.5182	-1	15.61	2.18671	71.045	13.05	.4249	22.73	4.782	.4753	.9707	.3886
4.44	.3725	-2	.1841	-1	.2023	4.326	.5140	-1	15.74	2.187714	71.161	13.02	.4247	22.83	4.786	.4771	.9625	.3869
4.45	.3678	-2	.1825	-1	.2016	4.336	.5099	-1	15.87	2.188708	71.274	12.99	.4245	22.94	4.790	.4786	.9550	.3852
4.46	.3633	-2	.1806	-1	.2009	4.346	.5058	-1	16.01	2.18967	71.386	12.96	.4243	23.04	4.795	.4805	.9473	.3835
4.47	.3587	-2	.1782	-1	.2002	4.357	.5017	-1	16.15	2.19061	71.498	12.93	.4241	23.14	4.799	.4823	.9396	.3818
4.48	.3543	-2	.1766	-1	.1994	4.367	.4977	-1	16.28	2.191659	71.610	12.90	.4239	23.25	4.803	.4840	.9320	.3801
4.49	.3499	-1	.1761	-1	.1987	4.377	.4937	-1	16.42	2.192632	71.721	12.87	.4237	23.35	4.808	.4858	.9244	.3785
4.50	.3455	-2	.1745	-1	.1980	4.387	.4898	-1	16.56	2.193600	71.832	12.84	.4236	23.46	4.812	.4875	.9170	.3768
4.51	.3412	-2	.1729	-1	.1973	4.398	.4859	-1	16.70	2.194563	71.942	12.81	.4234	23.56	4.816	.4893	.9096	.3752
4.52	.3370	-2	.1714	-1	.1966	4.408	.4820	-1	16.84	2.195520	72.052	12.78	.4232	23.67	4.820	.4910	.9022	.3735
4.53	.3329	-2	.1699	-1	.1959	4.418	.4781	-1	16.99	2.196473	72.162	12.75	.4230	23.77	4.824	.4926	.8950	.3719
4.54	.3288	-2	.1684	-1	.1952	4.426	.4743	-1	17.13	2.197420	72.2							

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{V}{a_1}$	$\nu$	$\mu$	$M_1$	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t_2}}{p_{t_1}}$	$\frac{p_{r_2}}{p_{r_1}}$					
4.85	.2255	-1	.1287	-1	.1753	4.746	.3714	-1	22.15	2.224155	75.482	11.90	.4173	27.28	4.948	5.512	.6936	-1	.3252	-1
4.86	.2229	-1	.1276	-1	.1747	4.756	.3685	-1	22.33	2.225257	75.580	11.87	.4173	27.39	4.952	5.531	.6882	-1	.3239	-1
4.87	.2202	-1	.1265	-1	.1741	4.766	.3657	-1	22.51	2.226055	75.678	11.85	.4172	27.50	4.955	5.550	.6828	-1	.3226	-1
4.88	.2177	-1	.1254	-1	.1735	4.776	.3628	-1	22.70	2.226848	75.775	11.83	.4170	27.62	4.959	5.569	.6773	-1	.3213	-1
4.89	.2151	-1	.1244	-1	.1729	4.787	.3600	-1	22.88	2.227638	75.872	11.80	.4169	27.73	4.962	5.588	.6722	-1	.3200	-1
4.90	.2126	-2	.1233	-1	.1724	4.797	.3573	-1	23.07	2.228424	75.969	11.78	.4167	27.85	4.966	5.607	.6670	-1	.3187	-1
4.91	.2101	-2	.1223	-1	.1718	4.807	.3545	-1	23.25	2.229206	76.066	11.75	.4165	27.96	4.969	5.626	.6616	-1	.3174	-1
4.92	.2076	-2	.1213	-1	.1712	4.817	.3518	-1	23.44	2.229984	76.162	11.73	.4164	28.07	4.973	5.646	.6567	-1	.3161	-1
4.93	.2052	-2	.1202	-1	.1706	4.826	.3491	-1	23.63	2.230758	76.258	11.70	.4163	28.19	4.976	5.665	.6516	-1	.3149	-1
4.94	.2028	-2	.1192	-1	.1700	4.838	.3464	-1	23.82	2.231528	76.353	11.68	.4161	28.30	4.980	5.684	.6465	-1	.3136	-1
4.95	.2004	-2	.1182	-1	.1695	4.848	.3437	-1	24.02	2.232294	76.449	11.66	.4160	28.42	4.983	5.703	.6415	-1	.3124	-1
4.96	.1981	-2	.1173	-1	.1689	4.858	.3411	-1	24.21	2.233056	76.544	11.63	.4158	28.54	4.987	5.723	.6346	-1	.3111	-1
4.97	.1957	-2	.1163	-1	.1683	4.865	.3385	-1	24.41	2.233815	76.638	11.61	.4157	28.65	4.990	5.742	.6317	-1	.3099	-1
4.98	.1935	-2	.1153	-1	.1678	4.879	.3359	-1	24.60	2.234570	76.732	11.58	.4155	28.77	4.993	5.761	.6294	-1	.3087	-1
4.99	.1912	-2	.1144	-1	.1672	4.889	.3333	-1	24.80	2.235321	76.826	11.56	.4154	28.88	4.997	5.781	.6220	-1	.3075	-1
5.00	.1890	-2	.1134	-1	.1667	4.899	.3308	-1	25.00	2.236068	76.920	11.54	.4152	29.00	5.000	5.800	.6172	-1	.3062	-1
5.01	.1868	-2	.1125	-1	.1661	4.909	.3282	-1	25.20	2.236811	77.013	11.51	.4151	29.12	5.003	5.820	.6124	-1	.3051	-1
5.02	.1847	-2	.1115	-1	.1656	4.919	.3257	-1	25.40	2.237551	77.106	11.49	.4149	29.23	5.007	5.829	.6077	-1	.3039	-1
5.03	.1825	-2	.1106	-1	.1650	4.930	.3233	-1	25.61	2.238287	77.199	11.47	.4148	29.35	5.010	5.839	.6030	-1	.3027	-1
5.04	.1801	-2	.1097	-1	.1645	4.940	.3208	-1	25.81	2.239020	77.291	11.44	.4147	29.47	5.013	5.878	.5981	-1	.3015	-1
5.05	.1783	-2	.1085	-1	.1639	4.950	.3184	-1	26.02	2.239749	77.385	11.42	.4145	29.59	5.016	5.898	.5938	-1	.3003	-1
5.06	.1763	-2	.1079	-1	.1634	4.960	.3159	-1	26.22	2.240474	77.477	11.40	.4144	29.70	5.020	5.918	.5893	-1	.2991	-1
5.07	.1742	-2	.1070	-1	.1628	4.970	.3135	-1	26.43	2.241195	77.568	11.38	.4142	29.82	5.023	5.937	.5848	-1	.2980	-1
5.08	.1722	-2	.1061	-1	.1623	4.981	.3112	-1	26.64	2.241914	77.660	11.35	.4141	29.94	5.026	5.957	.5803	-1	.2968	-1
5.09	.1703	-2	.1053	-1	.1618	4.991	.3088	-1	26.86	2.242628	77.751	11.33	.4140	30.06	5.029	5.977	.5759	-1	.2957	-1
5.10	.1683	-2	.1044	-1	.1612	5.001	.3065	-1	27.07	2.243339	77.841	11.31	.4138	30.18	5.033	5.997	.5715	-1	.2945	-1
5.11	.1664	-2	.1035	-1	.1607	5.011	.3042	-1	27.28	2.244047	77.931	11.29	.4137	30.30	5.036	6.016	.5672	-1	.2934	-1
5.12	.1645	-2	.1027	-1	.1602	5.021	.3019	-1	27.50	2.244751	78.021	11.26	.4136	30.42	5.039	6.036	.5628	-1	.2923	-1
5.13	.1626	-2	.1019	-1	.1597	5.032	.2996	-1	27.72	2.245451	78.111	11.24	.4134	30.54	5.042	6.056	.5586	-1	.2911	-1
5.14	.1608	-2	.1010	-1	.1591	5.042	.2973	-1	27.94	2.246148	78.201	11.22	.4133	30.66	5.045	6.076	.5543	-1	.2900	-1
5.15	.1589	-2	.1002	-1	.1586	5.052	.2951	-1	28.16	2.246842	78.290	11.20	.4132	30.78	5.048	6.096	.5501	-1	.2889	-1
5.16	.1571	-2	.9939	-2	.1581	5.062	.2929	-1	28.38	2.247532	78.379	11.18	.4130	30.90	5.051	6.117	.5460	-1	.2878	-1
5.17	.1553	-2	.9858	-2	.1576	5.072	.2907	-1	28.60	2.248219	78.468	11.15	.4129	31.02	5.054	6.137	.5418	-1	.2867	-1
5.18	.1536	-2	.9778	-2	.1571	5.083	.2885	-1	28.83	2.248903	78.556	11.13	.4128	31.14	5.058	6.157	.5377	-1	.2856	-1
5.19	.1518	-2	.9699	-2	.1566	5.093	.2863	-1	29.06	2.249583	78.645	11.11	.4126	31.26	5.061	6.177	.5337	-1	.2845	-1
5.20	.1501	-2	.9620	-2	.1561	5.103	.2842	-1	29.28	2.250260	78.733	11.09	.4125	31.38	5.064	6.197	.5297	-1	.2834	-1
5.21	.1484	-2	.9543	-2	.1555	5.113	.2821	-1	29.51	2.250934	78.820	11.07	.4124	31.50	5.067	6.217	.5257	-1	.2824	-1
5.22	.1468	-2	.9466	-2	.1550	5.123	.2799	-1	29.74	2.251604	78.908	11.04	.4123	31.62	5.070	6.238	.5217	-1	.2811	-1
5.23	.1451	-2	.9389	-2	.1545	5.134	.2778	-1	29.98	2.252271	78.995	11.02	.4121	31.75	5.073	6.258	.5178	-1	.2800	-1
5.24	.1435	-2	.9314	-2	.1540	5.144	.2758	-1	30.21	2.252935	79.081	11.00	.4120	31.87	5.076	6.278	.5139	-1	.2791	-1
5.25	.1419	-2	.9239	-2	.1536	5.154	.2737	-1	30.45	2.253596	79.167	10.98	.4119	31.99	5.079	6.299	.5100	-1	.2782	-1
5.26	.1403	-2	.9165	-2	.1531	5.164	.2717	-1	30.68	2.254254	79.254	10.96	.4118	32.11	5.082	6.319	.5062	-1	.2771	-1
5.27	.1387	-2	.9092	-2	.1526	5.174	.2697	-1	30.92	2.254908	79.340	10.94	.4116	32.24	5.085	6.340	.5024	-1	.2761	-1
5.28	.1372	-2	.9019	-2	.1521	5.184	.2677	-1	31.16	2.255559	79.426	10.92	.4115	32.36	5.088	6.360	.4987	-1	.2750	-1
5.29	.1356	-2	.8947	-2	.1516	5.195	.2657	-1	31.41	2.256207	79.511	10.90	.4114	32.48	5.090	6.381	.4950	-1	.2740	-1
5.30	.1341	-2	.8875	-2	.1511	5.205	.2637	-1	31.65	2.256852	79.597	10.88	.4113	32.61	5.093	6.401	.4913	-1	.2730	-1
5.31	.1326	-2	.8805	-2	.1506	5.215	.2617	-1	31.89	2.257494	79.681	10.86	.4112	32.73	5.096	6.422	.4876	-1	.2720	-1
5.32	.1311	-2	.8734	-2	.1501	5.225	.2594	-1	32.14	2.258133	79.765	10.83	.4110	32.85	5.099	6.443	.4840	-1	.2710	-1
5.33	.1297	-2	.8665	-2	.1497	5.235	.2579	-1	32.39	2.258769	79.850	10.81	.4109	32.98	5.102	6.464	.4804	-1	.2700	-1
5.34	.1282	-2	.8596	-2	.1492	5.246	.2560	-1	32.64	2.259401	79.934	10.79	.4108	33.10	5.105	6.484	.4768	-1	.2690	-1
5.35	.1268	-2	.8528	-2	.1487	5.256	.2541	-1	32.89	2.260031	80.018	10.77	.4107	33.23	5.108	6.505	.4733	-1	.2680	-1
5.36	.1254	-2	.8461	-2	.1482	5.266	.2522	-1	33.14	2.260658	80.101	10.75	.4106	33.35	5.111	6.526	.4697	-1	.2670	-1
5.37	.1240	-2	.8394	-2	.1478	5.276	.2504	-1	33.40	2.261281	80.185	10.73	.4104	33.48	5.113	6.547	.4663	-1	.2660	-1
5.38	.1227	-2	.8327	-2	.1473	5.286	.2485	-1	33.66	2.261902	80.268	10.71	.4103	33.60	5.116	6.568	.4628	-1	.2650	-1
5.39	.1213	-2	.8262	-2	.1468	5.296	.2467	-1	33.91	2.262520	80.351	10.69	.4102	33.73	5.119	6.589	.4594	-1	.2641	-1
5.40	.1200	-2	.8197</td																	

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

γ = 7/5

<i>M</i> or <i>M</i> <sub>1</sub>	<i>p</i> <i>p</i> <sub>1</sub>	<i>p</i> <i>p</i> <sub>1</sub>	<i>T</i> <i>T</i> <sub>1</sub>	<i>β</i>	<i>q</i> <i>p</i> <sub>1</sub>	<i>A</i> <i>A</i> <sub>1</sub>	<i>V</i> <i>a</i> <sub>1</sub>	<i>v</i>	<i>μ</i>	<i>M</i> <sub>2</sub>	<i>p</i> <sub>2</sub> <i>p</i> <sub>1</sub>	<i>p</i> <sub>2</sub> <i>p</i> <sub>1</sub>	<i>T</i> <sub>2</sub> <i>T</i> <sub>1</sub>	<i>p</i> <sub>1</sub> <i>p</i> <sub>2</sub>	<i>p</i> <sub>1</sub> <i>p</i> <sub>2</sub>					
5.75	.8216	-1	.6254	-2	1314	5.662	.1902	-1	44.40	2.282942	83.169	10.02	.4064	.3541	5.212	7.369	.3536	-1	.2324	-1
5.76	.8130	-1	.6207	-2	1310	5.673	.1888	-1	44.72	2.283462	83.243	9.998	.4063	.3854	5.214	7.392	.3510	-1	.2316	-1
5.77	.8044	-1	.6161	-2	1306	5.683	.1875	-1	45.05	2.283980	83.317	9.980	.4062	.3865	5.217	7.414	.3486	-1	.2308	-1
5.78	.7960	-1	.6114	-2	1302	5.693	.1862	-1	45.38	2.284496	83.391	9.963	.4061	.3881	5.219	7.436	.3461	-1	.2300	-1
5.79	.7876	-1	.6069	-2	1298	5.703	.1845	-1	45.72	2.285009	83.463	9.946	.4060	.3894	5.221	7.459	.3436	-1	.2292	-1
5.80	.7794	-1	.6023	-2	1294	5.713	.1835	-1	46.05	2.285520	83.537	9.928	.4059	.3908	5.224	7.481	.3412	-1	.2284	-1
5.81	.7713	-1	.5978	-2	1290	5.723	.1823	-1	46.39	2.286029	83.609	9.911	.4059	.3922	5.226	7.504	.3388	-1	.2277	-1
5.82	.7632	-1	.5934	-2	1286	5.733	.1810	-1	46.72	2.286535	83.683	9.894	.4058	.3935	5.228	7.527	.3364	-1	.2269	-1
5.83	.7553	-1	.5889	-2	1282	5.744	.1797	-1	47.07	2.287040	83.755	9.877	.4057	.3949	5.231	7.549	.3340	-1	.2261	-1
5.84	.7474	-1	.5846	-2	1279	5.754	.1784	-1	47.41	2.287542	83.827	9.860	.4056	.3962	5.233	7.572	.3317	-1	.2254	-1
5.85	.7396	-1	.5802	-2	1275	5.764	.1772	-1	47.75	2.288041	83.899	9.842	.4055	.3976	5.235	7.595	.3293	-1	.2246	-1
5.86	.7320	-1	.5759	-2	1271	5.774	.1760	-1	48.10	2.288539	83.971	9.826	.4054	.3990	5.237	7.618	.3270	-1	.2238	-1
5.87	.7244	-1	.5716	-2	1267	5.784	.1747	-1	48.45	2.289034	84.042	9.809	.4053	.4003	5.240	7.640	.3247	-1	.2231	-1
5.88	.7169	-1	.5674	-2	1263	5.794	.1735	-1	48.80	2.289527	84.114	9.792	.4052	.4017	5.242	7.663	.3225	-1	.2223	-1
5.89	.7095	-1	.5632	-2	1260	5.804	.1723	-1	49.15	2.290018	84.185	9.775	.4051	.4031	5.244	7.686	.3202	-1	.2216	-1
5.90	.7021	-1	.5590	-2	1256	5.815	.1711	-1	49.51	2.290507	84.257	9.758	.4050	.4045	5.246	7.709	.3180	-1	.2208	-1
5.91	.6949	-1	.5549	-2	1252	5.825	.1699	-1	49.86	2.290993	84.327	9.742	.4049	.4058	5.249	7.732	.3157	-1	.2201	-1
5.92	.6877	-1	.5508	-2	1249	5.835	.1687	-1	50.22	2.291477	84.398	9.725	.4049	.4072	5.251	7.755	.3135	-1	.2194	-1
5.93	.6807	-1	.5468	-2	1245	5.845	.1676	-1	50.59	2.291960	84.468	9.706	.4048	.4086	5.253	7.778	.3113	-1	.2186	-1
5.94	.6737	-1	.5428	-2	1241	5.855	.1664	-1	50.95	2.292440	84.539	9.692	.4047	.4100	5.255	7.801	.3092	-1	.2179	-1
5.95	.6668	-1	.5388	-2	1238	5.865	.1652	-1	51.32	2.292918	84.609	9.675	.4046	.4114	5.257	7.824	.3070	-1	.2172	-1
5.96	.6599	-1	.5348	-2	1234	5.876	.1641	-1	51.68	2.293394	84.679	9.659	.4045	.4128	5.260	7.847	.3049	-1	.2165	-1
5.97	.6532	-1	.5309	-2	1230	5.886	.1630	-1	52.05	2.293867	84.748	9.643	.4044	.4141	5.262	7.871	.3028	-1	.2157	-1
5.98	.6465	-1	.5270	-2	1227	5.896	.1618	-1	52.43	2.294339	84.817	9.626	.4043	.4155	5.264	7.894	.3007	-1	.2150	-1
5.99	.6399	-1	.5232	-2	1223	5.906	.1607	-1	52.80	2.294809	84.887	9.610	.4042	.4169	5.266	7.917	.2986	-1	.2143	-1
6.00	.6334	-1	.5194	-2	1220	5.916	.1596	-1	53.18	2.295276	84.955	9.594	.4041	.4183	5.268	7.941	.2965	-1	.2136	-1
6.01	.6269	-1	.5156	-2	1216	5.926	.1585	-1	53.56	2.295742	85.025	9.578	.4041	.4197	5.270	7.964	.2945	-1	.2129	-1
6.02	.6205	-1	.5118	-2	1212	5.936	.1574	-1	53.91	2.296205	85.093	9.562	.4040	.4211	5.273	7.987	.2924	-1	.2122	-1
6.03	.6142	-1	.5081	-2	1209	5.947	.1563	-1	54.32	2.296667	85.162	9.546	.4039	.4225	5.275	8.011	.2904	-1	.2115	-1
6.04	.6080	-1	.5044	-2	1205	5.957	.1553	-1	54.71	2.297126	85.230	9.530	.4038	.4240	5.277	8.034	.2884	-1	.2108	-1
6.05	.6018	-1	.5008	-2	1202	5.967	.1542	-1	55.10	2.297583	85.297	9.514	.4037	.4254	5.279	8.058	.2864	-1	.2101	-1
6.06	.5957	-1	.4971	-2	1198	5.977	.1531	-1	55.49	2.298039	85.366	9.498	.4037	.4268	5.281	8.081	.2844	-1	.2094	-1
6.07	.5897	-1	.4935	-2	1195	5.987	.1521	-1	55.88	2.298492	85.433	9.482	.4036	.4282	5.283	8.105	.2825	-1	.2088	-1
6.08	.5838	-1	.4900	-2	1191	5.997	.1511	-1	56.28	2.298944	85.500	9.467	.4035	.4296	5.285	8.129	.2806	-1	.2081	-1
6.09	.5779	-1	.4864	-2	1188	6.007	.1500	-1	56.68	2.299393	85.568	9.451	.4034	.4310	5.287	8.152	.2786	-1	.2074	-1
6.10	.5721	-1	.4829	-2	1185	6.017	.1490	-1	57.08	2.299841	85.635	9.435	.4033	.4325	5.289	8.176	.2767	-1	.2067	-1
6.11	.5663	-1	.4785	-2	1181	6.028	.1480	-1	57.48	2.300266	85.702	9.420	.4033	.4339	5.291	8.200	.2748	-1	.2061	-1
6.12	.5606	-1	.4760	-2	1178	6.038	.1470	-1	57.88	2.300730	85.768	9.404	.4032	.4353	5.293	8.223	.2730	-1	.2054	-1
6.13	.5550	-1	.4726	-2	1174	6.048	.1460	-1	58.29	2.301172	85.834	9.389	.4031	.4367	5.295	8.247	.2711	-1	.2047	-1
6.14	.5494	-1	.4692	-2	1171	6.058	.1450	-1	58.70	2.301612	85.901	9.373	.4030	.4382	5.297	8.271	.2692	-1	.2041	-1
6.15	.5439	-1	.4658	-2	1168	6.068	.1440	-1	59.11	2.302050	85.967	9.358	.4029	.4396	5.299	8.295	.2674	-1	.2034	-1
6.16	.5385	-1	.4625	-2	1164	6.078	.1430	-1	59.53	2.302486	86.033	9.343	.4029	.4410	5.301	8.319	.2656	-1	.2021	-1
6.17	.5331	-1	.4592	-2	1161	6.088	.1421	-1	59.94	2.302920	86.099	9.327	.4028	.4425	5.303	8.343	.2638	-1	.2015	-1
6.18	.5278	-1	.4559	-2	1158	6.099	.1411	-1	60.36	2.303353	86.164	9.312	.4027	.4439	5.305	8.367	.2620	-1	.2015	-1
6.19	.5225	-1	.4527	-2	1154	6.109	.1402	-1	60.79	2.303783	86.229	9.297	.4026	.4454	5.307	8.391	.2602	-1	.2008	-1
6.20	.5173	-1	.4495	-2	1151	6.119	.1392	-1	61.21	2.304212	86.295	9.282	.4025	.4468	5.309	8.415	.2584	-1	.2002	-1
6.21	.5122	-1	.4463	-2	1148	6.129	.1383	-1	61.64	2.304639	86.360	9.267	.4025	.4482	5.311	8.439	.2567	-1	.1995	-1
6.22	.5071	-1	.4431	-2	1144	6.139	.1373	-1	62.07	2.305064	86.424	9.252	.4024	.4497	5.313	8.464	.2550	-1	.1989	-1
6.23	.5021	-1	.4400	-2	1141	6.149	.1364	-1	62.50	2.305487	86.490	9.237	.4023	.4512	5.315	8.488	.2532	-1	.1983	-1
6.24	.4971	-1	.4369	-2	1138	6.159	.1355	-1	62.93	2.305908	86.554	9.222	.4022	.4526	5.317	8.512	.2515	-1	.1977	-1
6.25	.4922	-1	.4338	-2	1135	6.169	.1346	-1	63.37	2.306328	86.618	9.207	.4022	.4541	5.319	8.536	.2498	-1	.1970	-1
6.26	.4874	-1	.4307	-2	1132	6.180	.1337	-1	63.81	2.306746	86.683	9.192	.4021	.4555	5.321	8.561	.2482	-1	.1964	-1
6.27	.4825	-1	.4277	-2	1128	6.190	.1328	-1	64.25	2.307162	86.746	9.177	.4020	.4570	5.323	8.585	.2465	-1	.1958	-1
6.28	.4778	-1	.4246	-2	1125	6.200	.1319	-1	64.69	2.307576	86.810	9.163	.4019	.4584	5.325	8.610	.2448	-1	.1952	-1
6.29	.4731	-1	.4217	-2	1122	6.210	.1310	-1	65.14	2.307989	86.874	9.1								

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TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T}{T_1}$	$\theta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{1}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_1}{p_1}$	$\frac{p_1}{p_1}$					
6.65	.3341	-1	.3289	-1	1016	6.574	.1034	-1	83.03	2.321750	89.049	8.649	.3994	51.43	5.391	9.540	.1915	-1	1742	-1
6.66	.3309	-1	.3267	-1	1013	6.584	.1028	-1	83.58	2.322104	89.106	8.636	.3993	51.58	5.392	9.566	.1905	-1	1737	-1
6.67	.3278	-1	.3245	-1	1010	6.595	.1021	-1	84.13	2.322456	89.164	8.623	.3993	51.74	5.394	9.592	.1893	-1	1732	-1
6.68	.3247	-1	.3223	-1	1008	6.605	.1014	-1	84.68	2.322807	89.221	8.610	.3992	51.89	5.395	9.618	.1881	-1	1727	-1
6.69	.3217	-1	.3201	-2	1005	6.615	.1006	-1	85.24	2.323157	89.278	8.597	.3992	52.05	5.397	9.644	.1869	-1	1721	-1
6.70	.3187	-1	.3180	-2	1002	6.625	.1001	-1	85.80	2.323505	89.335	8.584	.3991	52.21	5.399	9.670	.1857	-1	1716	-1
6.71	.3157	-1	.3158	-2	9995	6.635	.9950	-2	86.37	2.323852	89.391	8.571	.3990	52.36	5.400	9.695	.1845	-1	1711	-1
6.72	.3127	-1	.3137	-2	9968	6.645	.9886	-2	86.94	2.324196	89.448	8.558	.3990	52.52	5.402	9.722	.1833	-1	1706	-1
6.73	.3098	-1	.3116	-2	9942	6.655	.9823	-2	87.51	2.324542	89.504	8.545	.3989	52.68	5.403	9.748	.1821	-1	1701	-1
6.74	.3069	-2	.3096	-2	9915	6.665	.9761	-2	88.08	2.324884	89.561	8.532	.3988	52.83	5.405	9.775	.1810	-1	1696	-1
6.75	.3041	-2	.3075	-2	9889	6.676	.9699	-1	88.66	2.325226	89.617	8.520	.3985	52.99	5.407	9.801	.1798	-1	1691	-1
6.76	.3013	-2	.3055	-2	9862	6.686	.9637	-1	89.24	2.325566	89.673	8.507	.3985	53.15	5.408	9.827	.1786	-1	1686	-1
6.77	.2985	-2	.3034	-2	9836	6.696	.9576	-2	89.82	2.325904	89.729	8.494	.3987	53.31	5.410	9.853	.1775	-1	1681	-1
6.78	.2957	-2	.3014	-2	9810	6.706	.9515	-1	90.41	2.326242	89.784	8.482	.3986	53.46	5.411	9.880	.1764	-1	1677	-1
6.79	.2930	-2	.2994	-2	9784	6.716	.9454	-1	91.00	2.326578	89.840	8.469	.3986	53.62	5.413	9.906	.1753	-1	1671	-1
6.80	.2902	-3	.2974	-2	9758	6.726	.9395	-1	91.59	2.326912	89.895	8.457	.3985	53.78	5.415	9.933	.1741	-1	1667	-1
6.81	.2876	-3	.2955	-2	9732	6.736	.9335	-1	92.19	2.327245	89.950	8.444	.3984	53.94	5.416	9.959	.1730	-1	1662	-1
6.82	.2849	-3	.2935	-2	9706	6.746	.9276	-1	92.79	2.327577	90.005	8.432	.3984	54.10	5.418	9.986	.1719	-1	1657	-1
6.83	.2823	-3	.2916	-2	9681	6.756	.9218	-1	93.39	2.327908	90.060	8.419	.3983	54.26	5.419	10.01	.1709	-1	1652	-1
6.84	.2797	-3	.2897	-2	9655	6.767	.9160	-2	94.00	2.328237	90.116	8.407	.3983	54.42	5.421	10.04	.1698	-1	1647	-1
6.85	.2771	-3	.2878	-2	9630	6.777	.9102	-2	94.61	2.328565	90.170	8.394	.3982	54.58	5.422	10.07	.1687	-1	1643	-1
6.86	.2746	-3	.2859	-2	9604	6.787	.9043	-1	95.22	2.328892	90.225	8.382	.3981	54.74	5.424	10.09	.1676	-1	1638	-1
6.87	.2720	-3	.2840	-2	9579	6.797	.9088	-2	95.83	2.329217	90.279	8.370	.3981	54.90	5.425	10.12	.1660	-1	1633	-1
6.88	.2696	-3	.2821	-2	9554	6.807	.9031	-2	96.45	2.329541	90.333	8.357	.3980	55.06	5.427	10.15	.1655	-1	1628	-1
6.89	.2671	-3	.2803	-2	9529	6.817	.8975	-2	97.08	2.329864	90.387	8.345	.3980	55.22	5.428	10.17	.1645	-1	1624	-1
6.90	.2646	-3	.2785	-2	9504	6.827	.8820	-2	97.70	2.330186	90.441	8.333	.3979	55.38	5.430	10.20	.1634	-1	1619	-1
6.91	.2622	-3	.2766	-2	9479	6.837	.8764	-2	98.33	2.330506	90.495	8.321	.3979	55.54	5.431	10.23	.1624	-1	1614	-1
6.92	.2598	-3	.2748	-2	9454	6.847	.8710	-2	98.96	2.330825	90.549	8.309	.3978	55.70	5.433	10.25	.1614	-1	1610	-1
6.93	.2575	-3	.2730	-2	9430	6.857	.8665	-2	99.60	2.331143	90.602	8.297	.3977	55.86	5.434	10.28	.1604	-1	1605	-1
6.94	.2551	-3	.2713	-2	9405	6.868	.8601	-2	100.2	2.331460	90.655	8.285	.3977	56.02	5.436	10.31	.1594	-1	1601	-1
6.95	.2528	-3	.2695	-2	9380	6.878	.8548	-2	100.9	2.331775	90.709	8.273	.3976	56.19	5.437	10.33	.1584	-1	1596	-1
6.96	.2505	-3	.2677	-2	9356	6.889	.8495	-2	101.5	2.332089	90.762	8.261	.3976	56.35	5.439	10.36	.1574	-1	1592	-1
6.97	.2482	-3	.2660	-2	9332	6.898	.8442	-2	102.2	2.332402	90.815	8.249	.3975	56.51	5.440	10.39	.1564	-1	1587	-1
6.98	.2460	-3	.2643	-2	9307	6.908	.8399	-2	102.8	2.332714	90.867	8.237	.3975	56.67	5.442	10.42	.1554	-1	1582	-1
6.99	.2438	-3	.2626	-2	9283	6.918	.8337	-2	103.5	2.333024	90.920	8.225	.3974	56.84	5.443	10.44	.1545	-1	1578	-1
7.00	.2416	-3	.2609	-2	9259	6.928	.8260	-2	104.1	2.333333	90.973	8.213	.3974	57.00	5.444	10.47	.1535	-1	1574	-1
7.01	.2394	-3	.2592	-2	9225	6.938	.8234	-1	104.8	2.333641	91.026	8.201	.3973	57.16	5.446	10.50	.1526	-1	1569	-1
7.02	.2372	-3	.2575	-2	9211	6.948	.8183	-1	105.5	2.333948	91.078	8.190	.3973	57.33	5.447	10.52	.1516	-1	1565	-1
7.03	.2351	-3	.2559	-2	9188	6.959	.8133	-1	106.1	2.334254	91.130	8.178	.3972	57.49	5.449	10.55	.1507	-1	1560	-1
7.04	.2330	-3	.2542	-2	9164	6.969	.8082	-2	106.8	2.334558	91.182	8.166	.3971	57.66	5.450	10.58	.1497	-1	1556	-1
7.05	.2309	-3	.2526	-2	9140	6.979	.8032	-2	107.5	2.334862	91.234	8.155	.3971	57.82	5.452	10.61	.1488	-1	1551	-1
7.06	.2288	-3	.2510	-2	9117	6.989	.7983	-2	108.2	2.335164	91.286	8.143	.3970	57.98	5.453	10.63	.1479	-1	1547	-1
7.07	.2267	-3	.2494	-2	9093	6.999	.7934	-2	109.0	2.335465	91.337	8.131	.3970	58.15	5.454	10.66	.1470	-1	1543	-1
7.08	.2247	-3	.2478	-2	9070	7.009	.7885	-2	109.5	2.335765	91.389	8.120	.3969	58.31	5.456	10.69	.1461	-1	1539	-1
7.09	.2227	-3	.2462	-2	9047	7.019	.7837	-2	110.2	2.336063	91.440	8.108	.3968	58.46	5.457	10.72	.1452	-1	1534	-1
7.10	.2207	-3	.2446	-2	9024	7.029	.7780	-2	110.9	2.336361	91.492	8.097	.3968	58.65	5.459	10.74	.1443	-1	1530	-1
7.11	.2187	-3	.2420	-2	9001	7.039	.7741	-2	111.6	2.336657	91.543	8.085	.3968	58.81	5.460	10.77	.1434	-1	1525	-1
7.12	.2168	-3	.2415	-2	8978	7.049	.7703	-2	112.3	2.336952	91.594	8.074	.3967	58.98	5.461	10.80	.1425	-1	1521	-1
7.13	.2149	-3	.2400	-2	8955	7.060	.7646	-2	113.0	2.337246	91.645	8.062	.3967	59.14	5.463	10.83	.1416	-1	1517	-1
7.14	.2130	-3	.2384	-2	8932	7.070	.7601	-2	113.7	2.337539	91.695	8.051	.3966	59.31	5.464	10.85	.1408	-1	1513	-1
7.15	.2111	-3	.2369	-2	8909	7.080	.7553	-2	114.5	2.337831	91.746	8.040	.3966	59.48	5.465	10.88	.1399	-1	1509	-1
7.16	.2092	-3	.2354	-2	8886	7.090	.7507	-2	115.2	2.338122	91.796	8.024	.3965	59.64	5.467	10.91	.1390	-1	1504	-1
7.17	.2073	-3	.2339	-2	8864	7.100	.7461	-2	115.9	2.338412	91.847	8.017	.3965	59.81	5.468	10.94	.1382	-1	1500	-1
7.18	.2055	-3	.2324	-2	8841	7.110	.7416	-2	116.6	2.338700	91.897	8.006	.3964	59.98	5.470	10.97	.1374	-1	1496	-1
7.19	.2037	-3	.2301	-2	8819	7.120	.7371	-2	117.3	2.339098	91.947	7.995	.3964	60.15	5.471	10.99	.1365	-1	1492	-1
7.20	.2019	-3	.2295	-2	8787	7.														

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{T}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{12}}{p_{11}}$	$\frac{p_2}{p_1}$						
7.55	.1489	-1	.1847	-2	.8064	-1	7.483	.5942	-2	146.2	2.348648	93.670	7.611	.3947	66.34	5.516	12.03	.1100	-1	.1354	-1
7.56	.1477	-1	.1836	-2	.8045	-1	7.494	.5908	-2	147.0	2.348899	93.716	7.601	.3946	66.51	5.517	12.06	.1093	-1	.1351	-1
7.57	.1464	-1	.1824	-2	.8025	-1	7.504	.5873	-2	147.9	2.349148	93.762	7.591	.3946	66.69	5.518	12.09	.1087	-1	.1347	-1
7.58	.1452	-1	.1813	-2	.8006	-1	7.514	.5839	-2	148.8	2.349397	93.807	7.581	.3946	66.87	5.520	12.11	.1081	-1	.1343	-1
7.59	.1439	-1	.1802	-2	.7986	-1	7.524	.5805	-2	149.7	2.349644	93.853	7.571	.3945	67.04	5.521	12.14	.1074	-1	.1340	-1
7.60	.1427	-1	.1792	-2	.7967	-1	7.534	.5771	-2	150.6	2.349891	93.895	7.561	.3945	67.22	5.522	12.17	.1068	-1	.1336	-1
7.61	.1415	-1	.1781	-2	.7948	-1	7.544	.5737	-2	151.5	2.350137	93.943	7.551	.3944	67.40	5.523	12.20	.1062	-1	.1333	-1
7.62	.1403	-1	.1770	-2	.7928	-1	7.554	.5704	-2	152.4	2.350382	93.988	7.541	.3944	67.58	5.524	12.23	.1056	-1	.1329	-1
7.63	.1391	-1	.1759	-2	.7909	-1	7.564	.5671	-2	153.3	2.350626	94.033	7.531	.3943	67.75	5.525	12.26	.1049	-1	.1326	-1
7.64	.1380	-1	.1749	-2	.7890	-1	7.574	.5638	-2	154.2	2.350869	94.078	7.521	.3943	67.93	5.527	12.29	.1043	-1	.1322	-1
7.65	.1368	-1	.1738	-2	.7871	-1	7.584	.5605	-2	155.1	2.351112	94.123	7.511	.3943	68.11	5.528	12.32	.1037	-1	.1319	-1
7.66	.1357	-1	.1728	-2	.7852	-1	7.594	.5572	-2	156.0	2.351353	94.168	7.501	.3942	68.29	5.529	12.35	.1031	-1	.1316	-1
7.67	.1345	-1	.1717	-2	.7833	-1	7.605	.5540	-2	157.0	2.351594	94.212	7.491	.3942	68.47	5.530	12.38	.1025	-1	.1312	-1
7.68	.1334	-1	.1707	-2	.7815	-1	7.615	.5508	-2	157.9	2.351834	94.257	7.482	.3941	68.65	5.531	12.41	.1019	-1	.1309	-1
7.69	.1323	-1	.1697	-2	.7790	-1	7.625	.5476	-2	158.8	2.352072	94.301	7.472	.3941	68.83	5.532	12.44	.1013	-1	.1305	-1
7.70	.1312	-1	.1687	-2	.7777	-1	7.635	.5445	-2	159.8	2.352310	94.345	7.462	.3941	69.01	5.533	12.47	.1008	-1	.1302	-1
7.71	.1301	-1	.1677	-2	.7759	-1	7.645	.5413	-2	160.7	2.352548	94.389	7.452	.3940	69.18	5.534	12.50	.1002	-1	.1299	-1
7.72	.1290	-1	.1667	-2	.7740	-1	7.655	.5382	-2	161.7	2.352784	94.433	7.443	.3940	69.36	5.536	12.53	.9959	-2	.1295	-1
7.73	.1279	-1	.1657	-2	.7722	-1	7.665	.5351	-2	162.6	2.353019	94.477	7.433	.3939	69.55	5.537	12.56	.9902	-2	.1292	-1
7.74	.1269	-1	.1647	-2	.7703	-1	7.675	.5320	-2	163.6	2.353254	94.521	7.423	.3939	69.73	5.538	12.59	.9845	-2	.1289	-1
7.75	.1258	-1	.1637	-2	.7685	-1	7.685	.5290	-2	164.5	2.353488	94.565	7.414	.3939	69.91	5.539	12.62	.9784	-2	.1285	-1
7.76	.1248	-1	.1627	-2	.7667	-1	7.695	.5259	-2	165.5	2.353721	94.608	7.404	.3938	70.09	5.540	12.65	.9732	-2	.1282	-1
7.77	.1237	-1	.1618	-2	.7648	-1	7.705	.5229	-2	166.5	2.353953	94.652	7.395	.3938	70.27	5.541	12.68	.9676	-2	.1279	-1
7.78	.1227	-1	.1608	-2	.7630	-1	7.715	.5199	-2	167.4	2.354184	94.695	7.385	.3937	70.45	5.542	12.71	.9620	-2	.1276	-1
7.79	.1217	-1	.1599	-2	.7612	-1	7.726	.5170	-2	168.4	2.354415	94.739	7.375	.3937	70.63	5.543	12.74	.9565	-2	.1272	-1
7.80	.1207	-1	.1589	-2	.7594	-1	7.736	.5140	-2	169.4	2.354644	94.782	7.366	.3937	70.81	5.544	12.77	.9510	-2	.1269	-1
7.81	.1197	-1	.1580	-2	.7576	-1	7.746	.5111	-2	170.4	2.354873	94.825	7.356	.3936	71.00	5.545	12.80	.9456	-2	.1266	-1
7.82	.1187	-1	.1571	-2	.7558	-1	7.756	.5082	-2	171.4	2.355101	94.868	7.347	.3936	71.18	5.547	12.83	.9402	-2	.1263	-1
7.83	.1177	-1	.1561	-2	.7540	-1	7.766	.5053	-2	172.4	2.355328	94.911	7.338	.3935	71.36	5.548	12.86	.9348	-2	.1259	-1
7.84	.1168	-1	.1552	-2	.7523	-1	7.776	.5024	-2	173.4	2.355555	94.954	7.328	.3935	71.54	5.549	12.89	.9295	-2	.1256	-1
7.85	.1158	-1	.1543	-2	.7505	-1	7.786	.4995	-2	174.4	2.355780	94.996	7.319	.3935	71.73	5.550	12.92	.9242	-2	.1253	-1
7.86	.1149	-1	.1534	-2	.7487	-1	7.796	.4967	-2	175.4	2.356005	95.039	7.309	.3934	71.91	5.551	12.96	.9189	-2	.1250	-1
7.87	.1139	-1	.1525	-2	.7470	-1	7.806	.4939	-2	176.4	2.356229	95.082	7.300	.3934	72.09	5.552	12.99	.9137	-2	.1247	-1
7.88	.1130	-1	.1516	-2	.7452	-1	7.816	.4911	-2	177.5	2.356453	95.124	7.291	.3933	72.28	5.553	13.02	.9055	-2	.1244	-1
7.89	.1121	-1	.1507	-2	.7435	-1	7.826	.4883	-2	178.5	2.356675	95.166	7.281	.3933	72.46	5.554	13.05	.9033	-2	.1241	-1
7.90	.1111	-1	.1498	-2	.7417	-1	7.836	.4855	-2	179.5	2.356897	95.208	7.272	.3933	72.65	5.555	13.08	.8982	-2	.1237	-1
7.91	.1102	-1	.1490	-2	.7400	-1	7.847	.4828	-2	180.5	2.357118	95.251	7.263	.3932	72.83	5.556	13.11	.8931	-2	.1234	-1
7.92	.1093	-1	.1481	-2	.7383	-1	7.857	.4800	-2	181.6	2.357338	95.293	7.254	.3932	73.01	5.557	13.14	.8880	-2	.1231	-1
7.93	.1084	-1	.1472	-2	.7365	-1	7.867	.4774	-2	182.6	2.357557	95.334	7.245	.3932	73.20	5.558	13.17	.8830	-2	.1228	-1
7.94	.1076	-1	.1464	-2	.7348	-1	7.877	.4747	-2	183.7	2.357776	95.376	7.235	.3931	73.38	5.559	13.20	.8780	-2	.1225	-1
7.95	.1067	-1	.1455	-2	.7331	-1	7.887	.4720	-2	184.7	2.357994	95.418	7.226	.3931	73.57	5.560	13.23	.8731	-2	.1222	-1
7.96	.1058	-1	.1447	-2	.7314	-1	7.897	.4693	-2	185.8	2.358211	95.460	7.217	.3930	73.76	5.561	13.26	.8682	-2	.1219	-1
7.97	.1050	-1	.1438	-2	.7297	-1	7.907	.4667	-2	186.9	2.358427	95.501	7.208	.3930	73.94	5.562	13.29	.8633	-2	.1216	-1
7.98	.1041	-1	.1430	-2	.7280	-1	7.917	.4641	-2	188.0	2.358642	95.542	7.199	.3930	74.13	5.563	13.33	.8584	-2	.1213	-1
7.99	.1033	-1	.1422	-2	.7263	-1	7.927	.4615	-2	189.0	2.358857	95.584	7.190	.3929	74.31	5.564	13.36	.8536	-2	.1210	-1
8.00	.1024	-1	.1414	-2	.7246	-1	7.937	.4588	-2	190.1	2.359071	95.625	7.181	.3929	74.50	5.565	13.39	.8488	-2	.1207	-1
8.01	.1016	-1	.1405	-2	.7230	-1	7.947	.4563	-2	191.2	2.359285	95.666	7.172	.3928	74.69	5.566	13.42	.8440	-2	.1204	-1
8.02	.1008	-1	.1397	-2	.7213	-1	7.957	.4538	-2	192.3	2.359497	95.707	7.163	.3928	74.87	5.567	13.45	.8393	-2	.1201	-1
8.03	.9997	-1	.1389	-2	.7196	-1	7.967	.4512	-2	193.4	2.359709	95.748	7.154	.3928	75.06	5.568	13.48	.8346	-2	.1198	-1
8.04	.9916	-1	.1381	-2	.7180	-1	7.978	.4487	-2	194.5	2.359920	95.789	7.145	.3927	75.25	5.569	13.51	.8299	-2	.1195	-1
8.05	.9837	-1	.1373	-2	.7163	-1	7.988	.4462	-2	195.6	2.360130	95.830	7.136	.3927	75.44	5.570	13.54	.8253	-2	.1192	-1
8.06	.9758	-1	.1365	-2	.7147	-1	7.998	.4437	-2	196.7	2.360340	95.871	7.127	.3927	75.62	5.571	13.57	.8207	-2	.1189	-1
8.07	.9679	-1	.1358	-2	.7130	-1	8.008	.4413	-2	197.8	2.360549	95.911	7.118	.3926	75.81	5.572	13.61	.8161	-2	.1186	-1
8.08	.9602	-1	.1350	-2	.7114	-1	8.018	.4388	-2	199.0	2.360757	95.951									

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TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{\rho}{p_1}$	$\frac{A}{A_1}$	$\frac{V}{a_\infty}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$				
8.45	.7170	-1	1096	-2	.6544	-1	8.191	.3584	-2	244.4	2.367983	97.388	6.797	.3914	83.14	5.607	14.83	.6025	-2	1082	-1
8.46	.7115	-1	1090	-2	.6530	-1	8.401	.3565	-2	245.7	2.368166	97.424	6.788	.3913	83.33	5.608	14.86	.6559	-2	1080	-1
8.47	.7060	-1	1084	-2	.6515	-1	8.411	.3545	-2	247.0	2.368348	97.462	6.780	.3913	83.53	5.609	14.89	.6554	-2	1077	-1
8.48	.7006	-1	1078	-2	.6501	-1	8.421	.3526	-2	248.4	2.368530	97.499	6.772	.3913	83.73	5.610	14.93	.6519	-2	1075	-1
8.49	.6952	-1	1072	-2	.6487	-1	8.431	.3508	-2	249.7	2.368712	97.536	6.764	.3912	83.93	5.611	14.96	.6484	-2	1072	-1
8.50	.6898	-1	1066	-2	.6472	-1	8.441	.3489	-2	251.1	2.368892	97.573	6.756	.3912	84.13	5.612	14.99	.6449	-2	1070	-1
8.51	.6846	-1	1060	-2	.6458	-1	8.451	.3470	-2	252.5	2.368972	97.609	6.748	.3912	84.32	5.613	15.02	.6415	-2	1067	-1
8.52	.6793	-1	1054	-2	.6444	-1	8.461	.3452	-2	253.8	2.369152	97.646	6.740	.3911	84.52	5.613	15.06	.6390	-2	1065	-1
8.53	.6741	-1	1048	-2	.6430	-1	8.471	.3433	-2	255.2	2.369341	97.683	6.732	.3911	84.72	5.614	15.09	.6346	-2	1062	-1
8.54	.6690	-1	1043	-2	.6416	-1	8.481	.3415	-2	256.6	2.369609	97.719	6.725	.3911	84.92	5.615	15.12	.6313	-2	1060	-1
8.55	.6638	-1	1037	-2	.6402	-1	8.491	.3397	-2	258.0	2.369787	97.756	6.717	.3911	85.12	5.616	15.16	.6279	-2	1057	-1
8.56	.6588	-1	1031	-2	.6388	-1	8.501	.3379	-2	259.4	2.369964	97.792	6.709	.3910	85.32	5.617	15.19	.6246	-2	1055	-1
8.57	.6538	-1	1026	-2	.6374	-1	8.511	.3361	-2	260.8	2.370140	97.828	6.701	.3910	85.52	5.618	15.22	.6212	-2	1052	-1
8.58	.6488	-1	1020	-2	.6360	-1	8.522	.3343	-2	262.2	2.370316	97.865	6.693	.3910	85.72	5.618	15.26	.6179	-2	1050	-1
8.59	.6438	-1	1015	-2	.6346	-1	8.532	.3326	-2	263.6	2.370492	97.901	6.685	.3909	85.92	5.619	15.29	.6147	-2	1048	-1
8.60	.6390	-1	1009	-2	.6332	-1	8.542	.3308	-2	265.0	2.370667	97.937	6.677	.3909	86.12	5.620	15.32	.6114	-2	1045	-1
8.61	.6341	-1	1004	-2	.6319	-1	8.552	.3291	-2	266.4	2.370841	97.973	6.670	.3909	86.32	5.621	15.36	.6082	-2	1043	-1
8.62	.6293	-1	9981	-3	.6305	-1	8.562	.3273	-2	267.9	2.371015	98.009	6.662	.3909	86.52	5.622	15.39	.6050	-2	1040	-1
8.63	.6245	-1	9927	-3	.6291	-1	8.572	.3256	-2	269.3	2.371188	98.045	6.654	.3908	86.72	5.623	15.42	.6018	-2	1038	-1
8.64	.6196	-1	9873	-3	.6277	-1	8.582	.3239	-2	270.8	2.371360	98.081	6.646	.3908	86.92	5.623	15.46	.5956	-2	1035	-1
8.65	.6151	-1	9820	-3	.6264	-1	8.592	.3222	-2	272.2	2.371532	98.116	6.639	.3908	87.13	5.624	15.49	.5954	-2	1033	-1
8.66	.6105	-1	9767	-3	.6250	-1	8.602	.3205	-2	273.7	2.371704	98.152	6.631	.3907	87.33	5.625	15.53	.5933	-2	1031	-1
8.67	.6059	-1	9714	-3	.6237	-1	8.612	.3189	-2	275.1	2.371875	98.187	6.623	.3907	87.53	5.626	15.56	.5892	-2	1028	-1
8.68	.6013	-1	9662	-3	.6224	-1	8.622	.3171	-2	276.6	2.372045	98.223	6.616	.3907	87.73	5.627	15.59	.5861	-2	1026	-1
8.69	.5968	-1	9610	-3	.6210	-1	8.632	.3155	-2	278.1	2.372215	98.258	6.608	.3906	87.94	5.627	15.63	.5830	-2	1024	-1
8.70	.5923	-1	9558	-3	.6197	-1	8.642	.3138	-2	279.6	2.372384	98.293	6.600	.3906	88.14	5.628	15.66	.5799	-2	1021	-1
8.71	.5878	-1	9507	-3	.6183	-1	8.652	.3122	-2	281.1	2.372553	98.329	6.593	.3906	88.34	5.629	15.69	.5769	-2	1019	-1
8.72	.5834	-1	9456	-3	.6170	-1	8.662	.3105	-2	282.6	2.372721	98.364	6.585	.3906	88.54	5.630	15.73	.5739	-2	1017	-1
8.73	.5790	-1	9405	-3	.6157	-1	8.673	.3089	-2	284.1	2.372889	98.399	6.578	.3905	88.75	5.631	15.76	.5709	-2	1014	-1
8.74	.5747	-1	9355	-3	.6143	-1	8.683	.3073	-2	285.6	2.373056	98.434	6.570	.3905	88.95	5.631	15.80	.5679	-2	1012	-1
8.75	.5704	-1	9305	-3	.6130	-1	8.693	.3057	-2	287.1	2.373222	98.469	6.562	.3905	89.16	5.632	15.83	.5649	-2	1010	-1
8.76	.5661	-1	9255	-3	.6117	-1	8.703	.3041	-2	288.6	2.373388	98.504	6.555	.3905	89.36	5.633	15.86	.5620	-2	1007	-1
8.77	.5619	-1	9203	-3	.6104	-1	8.713	.3025	-2	290.1	2.373554	98.539	6.547	.3904	89.57	5.634	15.90	.5590	-2	1005	-1
8.78	.5577	-1	9150	-3	.6091	-1	8.723	.3010	-2	291.7	2.373719	98.573	6.540	.3904	89.77	5.635	15.93	.5561	-2	1003	-1
8.79	.5536	-1	9106	-3	.6078	-1	8.733	.2994	-2	293.2	2.373883	98.608	6.532	.3904	89.97	5.635	15.97	.5532	-2	1001	-1
8.80	.5494	-1	9059	-3	.6065	-1	8.743	.2978	-2	294.8	2.374047	98.642	6.525	.3903	90.18	5.636	16.00	.5504	-2	9983	-2
8.81	.5453	-1	9011	-3	.6052	-1	8.753	.2963	-2	296.3	2.374210	98.677	6.518	.3903	90.39	5.637	16.04	.5475	-2	9960	-2
8.82	.5413	-1	8963	-3	.6039	-1	8.763	.2948	-2	297.9	2.374373	98.711	6.510	.3903	90.59	5.638	16.07	.5447	-2	9938	-2
8.83	.5373	-1	8915	-3	.6026	-1	8.773	.2932	-2	299.5	2.374535	98.745	6.503	.3903	90.80	5.638	16.10	.5418	-2	9916	-2
8.84	.5333	-1	8868	-3	.6014	-1	8.783	.2917	-2	301.0	2.374697	98.780	6.495	.3902	91.00	5.639	16.14	.5390	-2	9893	-2
8.85	.5293	-1	8821	-3	.6001	-1	8.793	.2902	-2	302.6	2.374859	98.814	6.488	.3902	91.21	5.640	16.17	.5362	-2	9871	-1
8.86	.5254	-1	8774	-3	.5988	-1	8.803	.2887	-2	304.2	2.375019	98.848	6.481	.3902	91.42	5.641	16.21	.5335	-2	9849	-1
8.87	.5215	-1	8728	-3	.5975	-1	8.813	.2872	-2	305.8	2.375180	98.882	6.473	.3901	91.62	5.641	16.24	.5307	-2	9827	-1
8.88	.5177	-1	8682	-3	.5963	-1	8.824	.2857	-2	307.4	2.375339	98.916	6.466	.3901	91.83	5.642	16.28	.5280	-2	9805	-1
8.89	.5139	-1	8636	-3	.5950	-1	8.834	.2843	-2	309.0	2.375499	98.950	6.459	.3901	92.04	5.643	16.31	.5253	-2	9783	-1
8.90	.5101	-1	8590	-3	.5938	-1	8.844	.2828	-2	310.6	2.375657	98.984	6.451	.3901	92.25	5.644	16.35	.5226	-2	9761	-1
8.91	.5063	-1	8545	-3	.5925	-1	8.854	.2814	-2	312.3	2.375816	99.018	6.444	.3900	92.45	5.645	16.38	.5190	-2	9739	-1
8.92	.5026	-1	8500	-3	.5913	-1	8.864	.2799	-2	313.9	2.375973	99.051	6.437	.3900	92.66	5.645	16.41	.5172	-2	9718	-1
8.93	.4989	-1	8456	-3	.5900	-1	8.874	.2785	-2	315.5	2.376131	99.085	6.430	.3900	92.87	5.646	16.45	.5145	-2	9696	-1
8.94	.4952	-1	8411	-3	.5888	-1	8.884	.2771	-2	317.2	2.376287	99.119	6.422	.3900	93.08	5.647	16.48	.5119	-2	9675	-1
8.95	.4916	-1	8367	-3	.5875	-1	8.894	.2756	-2	318.8	2.376444	99.152	6.415	.3900	93.29	5.647	16.52	.5093	-2	9653	-1
8.96	.4880	-1	8323	-3	.5863	-1	8.904	.2742	-2	320.5	2.376599	99.186	6.408	.3900	93.50	5.648	16.55	.5067	-2	9631	-1
8.97	.4844	-1	8280	-3	.5851	-1	8.914	.2728	-2	322.1	2.376755	99.219	6.401	.3900	93.70	5.649	16.59	.5041	-2	9610	-1
8.98	.4809	-1	8236	-3	.5838	-1	8.924	.2714													

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 1.4$ 

$M$	$\frac{p}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{\eta}{p_1}$	$\frac{1}{1_s}$	$\frac{V}{a_s}$	$\nu$	$\mu$	$M_1$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_{12}}{p_1}$	$\frac{p_{12}}{p_1}$		
9.35	.3683	-1	.6997	-3	.5410	-1	9.295	.2254	-2	391.9	2.382311	100.436	6.140	.3889	101.8	5.675	17.94
9.36	.3657	-1	.6773	-3	.5399	-1	9.306	.2243	-2	392.9	2.382448	100.467	6.133	.3889	102.0	5.676	17.98
9.37	.3631	-1	.6739	-3	.5384	-1	9.316	.2232	-2	393.8	2.382585	100.495	6.127	.3889	102.3	5.677	18.01
9.38	.3605	-1	.6705	-3	.5377	-1	9.327	.2221	-2	394.8	2.382722	100.529	6.120	.3889	102.5	5.677	18.05
9.39	.3580	-1	.6671	-3	.5366	-1	9.337	.2210	-2	395.8	2.382859	100.559	6.113	.3888	102.7	5.678	18.09
9.40	.3555	-1	.6638	-3	.5356	-1	9.347	.2199	-2	400.8	2.382905	100.590	6.107	.3888	102.9	5.679	18.12
9.41	.3530	-1	.6604	-3	.5345	-1	9.357	.2188	-2	402.8	2.383130	100.620	6.100	.3888	103.1	5.679	18.16
9.42	.3505	-1	.6571	-3	.5334	-1	9.367	.2177	-2	404.8	2.383265	100.651	6.094	.3888	103.4	5.680	18.20
9.43	.3481	-1	.6535	-3	.5323	-1	9.377	.2167	-2	406.8	2.383400	100.681	6.087	.3888	103.6	5.681	18.23
9.44	.3456	-1	.6506	-3	.5313	-1	9.387	.2156	-2	408.8	2.383534	100.711	6.081	.3887	103.8	5.681	18.27
9.45	.3432	-1	.6473	-3	.5302	-1	9.397	.2146	-2	410.9	2.383668	100.742	6.074	.3887	104.0	5.682	18.31
9.46	.3408	-1	.6441	-3	.5291	-1	9.407	.2135	-2	412.9	2.383802	100.772	6.068	.3887	104.2	5.683	18.34
9.47	.3384	-1	.6409	-3	.5281	-1	9.417	.2125	-2	414.9	2.383935	100.802	6.062	.3887	104.5	5.683	18.38
9.48	.3361	-1	.6377	-3	.5270	-1	9.427	.2114	-2	417.0	2.384068	100.832	6.055	.3886	104.7	5.684	18.42
9.49	.3337	-1	.6345	-3	.5260	-1	9.437	.2103	-2	419.1	2.384120	100.862	6.049	.3886	104.9	5.684	18.45
9.50	.3314	-1	.6313	-3	.5249	-1	9.447	.2094	-2	421.1	2.384332	100.892	6.042	.3886	105.1	5.685	18.49
9.51	.3291	-1	.6282	-3	.5239	-1	9.457	.2084	-2	423.2	2.384464	100.922	6.036	.3886	105.3	5.686	18.53
9.52	.3266	-1	.6251	-3	.5228	-1	9.467	.2073	-2	425.3	2.384595	100.952	6.030	.3886	105.6	5.686	18.57
9.53	.3246	-1	.6220	-3	.5218	-1	9.477	.2063	-2	427.4	2.384726	100.981	6.023	.3885	105.8	5.687	18.60
9.54	.3223	-1	.6189	-3	.5208	-1	9.487	.2053	-2	429.5	2.384856	101.011	6.017	.3885	106.0	5.688	18.64
9.55	.3201	-1	.6158	-3	.5197	-1	9.498	.2043	-2	431.6	2.384986	101.041	6.011	.3885	106.2	5.688	18.68
9.56	.3179	-1	.6128	-3	.5187	-1	9.508	.2034	-2	433.7	2.385116	101.070	6.004	.3885	106.5	5.689	18.71
9.57	.3157	-1	.6098	-3	.5177	-1	9.518	.2024	-2	435.9	2.385245	101.100	5.998	.3884	106.7	5.690	18.75
9.58	.3135	-1	.6067	-3	.5167	-1	9.528	.2014	-2	438.0	2.385374	101.129	5.992	.3884	106.9	5.691	18.79
9.59	.3113	-1	.6037	-3	.5156	-1	9.538	.2004	-2	440.2	2.385502	101.159	5.985	.3884	107.1	5.691	18.83
9.60	.3092	-1	.6008	-3	.5140	-1	9.548	.1995	-2	442.3	2.385630	101.188	5.979	.3884	107.4	5.691	18.86
9.61	.3070	-1	.5978	-3	.5130	-1	9.558	.1985	-2	444.5	2.385759	101.217	5.973	.3884	107.6	5.692	18.90
9.62	.3049	-1	.5949	-3	.5120	-1	9.568	.1975	-2	446.7	2.385885	101.247	5.967	.3883	107.8	5.692	18.94
9.63	.3028	-1	.5919	-3	.5116	-1	9.578	.1966	-2	448.8	2.386012	101.276	5.960	.3883	108.0	5.693	18.98
9.64	.3007	-1	.5890	-3	.5106	-1	9.588	.1956	-2	451.0	2.386139	101.305	5.954	.3883	108.3	5.694	19.01
9.65	.2987	-1	.5861	-3	.5096	-1	9.598	.1947	-2	453.2	2.386265	101.334	5.948	.3883	108.5	5.694	19.05
9.66	.2966	-1	.5833	-3	.5086	-1	9.608	.1938	-2	455.4	2.386391	101.363	5.942	.3883	108.7	5.695	19.09
9.67	.2946	-1	.5804	-3	.5076	-1	9.618	.1928	-2	457.7	2.386516	101.392	5.936	.3882	108.9	5.695	19.13
9.68	.2926	-1	.5776	-3	.5066	-1	9.628	.1919	-2	459.9	2.386641	101.421	5.930	.3882	109.2	5.696	19.16
9.69	.2906	-1	.5747	-3	.5056	-1	9.638	.1910	-2	462.1	2.386766	101.450	5.923	.3882	109.4	5.697	19.20
9.70	.2886	-1	.5719	-3	.5046	-1	9.648	.1901	-2	464.4	2.386890	101.479	5.917	.3882	109.6	5.697	19.24
9.71	.2866	-1	.5691	-3	.5036	-1	9.658	.1892	-2	466.6	2.387014	101.507	5.911	.3882	109.8	5.698	19.28
9.72	.2847	-1	.5664	-3	.5026	-1	9.668	.1883	-2	468.9	2.387138	101.536	5.905	.3881	110.1	5.698	19.31
9.73	.2827	-1	.5636	-3	.5016	-1	9.678	.1874	-2	471.2	2.387261	101.561	5.899	.3881	110.3	5.699	19.35
9.74	.2808	-1	.5609	-3	.5007	-1	9.689	.1865	-2	473.4	2.387384	101.583	5.893	.3881	110.5	5.700	19.39
9.75	.2789	-1	.5581	-3	.4997	-1	9.699	.1856	-2	475.7	2.387507	101.621	5.887	.3881	110.7	5.700	19.43
9.76	.2770	-1	.5554	-3	.4987	-1	9.709	.1847	-2	478.0	2.387620	101.650	5.881	.3880	111.0	5.701	19.47
9.77	.2751	-1	.5527	-3	.4977	-1	9.719	.1838	-2	480.3	2.387751	101.678	5.875	.3880	111.2	5.702	19.50
9.78	.2733	-1	.5501	-3	.4968	-1	9.729	.1830	-2	482.6	2.387872	101.707	5.869	.3880	111.4	5.702	19.54
9.79	.2714	-1	.5474	-3	.4958	-1	9.739	.1821	-2	485.0	2.387993	101.735	5.863	.3880	111.7	5.703	19.58
9.80	.2696	-1	.5447	-3	.4949	-1	9.749	.1812	-2	487.3	2.388114	101.763	5.857	.3880	111.9	5.703	19.62
9.81	.2677	-1	.5421	-3	.4939	-1	9.759	.1804	-2	489.6	2.388244	101.791	5.851	.3879	112.1	5.704	19.66
9.82	.2659	-1	.5395	-3	.4929	-1	9.769	.1795	-2	492.0	2.388354	101.820	5.845	.3879	112.3	5.705	19.70
9.83	.2641	-1	.5369	-3	.4920	-1	9.779	.1787	-2	494.4	2.388474	101.846	5.839	.3879	112.6	5.705	19.73
9.84	.2624	-1	.5343	-3	.4910	-1	9.789	.1778	-2	496.7	2.388593	101.876	5.833	.3879	112.8	5.705	19.77
9.85	.2606	-1	.5317	-3	.4901	-1	9.799	.1770	-2	499.1	2.388712	101.904	5.827	.3879	113.0	5.706	19.81
9.86	.2588	-1	.5292	-3	.4891	-1	9.809	.1762	-2	501.5	2.388831	101.932	5.821	.3878	113.3	5.707	19.85
9.87	.2571	-1	.5266	-3	.4882	-1	9.819	.1753	-2	503.9	2.388949	101.960	5.815	.3878	113.5	5.707	19.89
9.88	.2554	-1	.5241	-3	.4873	-1	9.820	.1745	-2	506.3	2.389067	101.987	5.809	.3878	113.7	5.708	19.92
9.89	.2537	-1	.5216	-3	.4863	-1	9.830	.1737	-2	508.7	2.389185	102.015	5.803	.3878	113.9	5.708	19.96
9.90	.2520	-1	.5191	-3	.4854	-1	9.840	.1729	-2	511.2	2.389202	102.043	5.797	.3878	114.2	5.709	20.00
9.91	.2503	-1	.5166	-3	.4845	-1	9.850	.1720	-2	513.6	2.389419	102.070	5.792	.3877	114.4	5.710	20.04
9.92	.2486	-1	.5141	-3	.4835	-1	9.860	.1712	-2	516.0	2.389536	102.098	5.786	.3877	114.6	5.710	20.08
9.93	.2469	-1	.5117	-3	.4826	-1	9.880	.1704	-2	518.5	2.389652	102.126	5.780	.3877	114.9	5.710	20.12
9.94	.2453	-1	.5092	-3	.4817	-1	9.890	.1696	-2	520.1	2.389768	102.153	5.774	.3877	115.1	5.711	20.15
9.95	.2436	-1	.5068	-3	.4806	-1	9.900	.1688	-2	523.4	2.389884	102.180	5.768	.3877	115.3	5.712	20.19
9.96	.2420	-1	.5044	-3	.4798	-1	9.910	.1681	-2	525.9	2.389990	102.206	5.762	.3877	115.6	5.712	20.23
9.97	.2404	-1	.5020	-3	.4789	-1	9.920	.1673	-2	528.4	2.390114	102.235	5.756	.3876	115.8	5.713	20.27

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{1}{1_*$	$\frac{1^*}{a_*}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_{12}}{p_{11}}$	$\frac{p_1}{p_{12}}$					
10.50	.1701	-3	.3920	.4338	-1	10.45	.1313	-2	675.0	2.395766	103.61	5.465	.3867	128.5	5.740	22.38	.2422	-2	.7022	-2
10.52	.1679	-3	.3845	.4323	-1	10.47	.1301	-2	681.1	2.395964	103.66	5.455	.3867	129.0	5.741	22.46	.2400	-2	.6996	-2
10.54	.1658	-3	.3850	.4307	-1	10.49	.1249	-2	687.3	2.396160	103.71	5.444	.3866	129.4	5.742	22.54	.2379	-2	.6968	-2
10.56	.1637	-3	.3815	.4291	-1	10.51	.1278	-2	693.5	2.396355	103.76	5.434	.3866	129.9	5.743	22.63	.2356	-2	.6942	-2
10.58	.1616	-3	.3780	.4276	-1	10.53	.1267	-2	699.7	2.396550	103.81	5.424	.3866	130.4	5.744	22.71	.2337	-2	.6917	-2
10.60	.1596	-3	.3747	.4260	-1	10.55	.1255	-2	706.0	2.396743	103.86	5.413	.3865	130.9	5.744	22.79	.2317	-2	.6891	-2
10.62	.1576	-3	.3713	.4245	-1	10.57	.1244	-2	712.3	2.396935	103.90	5.403	.3865	131.4	5.745	22.87	.2296	-2	.6866	-2
10.64	.1556	-3	.3680	.4230	-1	10.59	.1233	-2	718.7	2.397126	103.96	5.393	.3865	131.9	5.746	22.96	.2276	-2	.6839	-2
10.66	.1537	-3	.3647	.4215	-1	10.61	.1223	-2	725.2	2.397316	104.01	5.383	.3864	132.4	5.747	23.04	.2256	-2	.6814	-2
10.68	.1518	-3	.3614	.4200	-1	10.63	.1212	-2	731.6	2.397505	104.05	5.373	.3864	132.9	5.748	23.12	.2236	-2	.6789	-2
10.70	.1499	-3	.3582	.4185	-1	10.65	.1201	-2	738.2	2.397693	104.10	5.363	.3864	133.4	5.749	23.21	.2216	-2	.6763	-2
10.72	.1480	-3	.3550	.4170	-1	10.67	.1191	-2	744.8	2.397880	104.14	5.353	.3863	133.9	5.750	23.29	.2197	-2	.6737	-2
10.74	.1462	-3	.3518	.4155	-1	10.69	.1180	-2	751.4	2.398066	104.19	5.343	.3863	134.4	5.751	23.37	.2178	-2	.6712	-2
10.76	.1444	-3	.3487	.4140	-1	10.71	.1170	-2	758.1	2.398251	104.24	5.333	.3863	134.9	5.752	23.46	.2159	-2	.6688	-2
10.78	.1426	-3	.3456	.4125	-1	10.73	.1160	-2	764.8	2.398435	104.29	5.323	.3862	135.4	5.753	23.54	.2140	-2	.6663	-2
10.80	.1408	-3	.3426	.4111	-1	10.75	.1150	-2	771.5	2.398618	104.33	5.313	.3862	135.9	5.753	23.62	.2121	-2	.6638	-2
10.82	.1391	-3	.3406	.4096	-1	10.77	.1140	-2	778.4	2.398801	104.38	5.303	.3862	136.4	5.754	23.71	.2103	-2	.6614	-2
10.84	.1374	-3	.3365	.4081	-1	10.79	.1130	-2	785.2	2.398992	104.43	5.293	.3862	136.9	5.755	23.79	.2085	-2	.6589	-2
10.86	.1357	-3	.3336	.4067	-1	10.81	.1120	-2	792.1	2.399182	104.48	5.283	.3861	137.4	5.756	23.88	.2067	-2	.6565	-2
10.88	.1340	-3	.3306	.4053	-1	10.83	.1110	-2	799.1	2.399371	104.52	5.274	.3861	137.9	5.757	23.96	.2048	-2	.6542	-2
10.90	.1324	-3	.3277	.4038	-1	10.85	.1101	-2	806.1	2.399519	104.57	5.264	.3861	138.5	5.758	24.05	.2031	-2	.6518	-2
10.92	.1307	-3	.3249	.4024	-1	10.87	.1091	-2	813.1	2.399697	104.61	5.254	.3860	139.0	5.759	24.13	.2013	-2	.6494	-2
10.94	.1291	-3	.3220	.4010	-1	10.89	.1082	-2	820.3	2.399873	104.66	5.245	.3860	139.5	5.759	24.21	.1996	-2	.6469	-2
10.96	.1276	-3	.3192	.4000	-1	10.91	.1073	-2	827.4	2.400049	104.71	5.235	.3860	140.0	5.760	24.30	.1979	-2	.6447	-2
10.98	.1260	-3	.3165	.3982	-1	10.93	.1064	-2	834.6	2.400223	104.75	5.225	.3860	140.5	5.761	24.39	.1962	-2	.6424	-2
11.00	.1245	-3	.3137	.3968	-1	10.95	.1054	-2	841.9	2.400397	104.80	5.216	.3859	141.0	5.762	24.47	.1945	-2	.6400	-2
11.02	.1230	-3	.3109	.3954	-1	10.97	.1045	-2	849.2	2.400570	104.85	5.206	.3859	141.5	5.763	24.56	.1921	-2	.6376	-2
11.04	.1215	-3	.3083	.3941	-1	11.00	.1036	-2	856.6	2.400741	104.89	5.197	.3859	142.0	5.764	24.64	.1912	-2	.6354	-2
11.06	.1200	-3	.3056	.3927	-1	11.02	.1028	-2	864.0	2.400912	104.93	5.188	.3858	142.5	5.764	24.73	.1896	-2	.6330	-2
11.08	.1186	-3	.3030	.3913	-1	11.04	.1019	-2	871.5	2.401082	104.98	5.178	.3858	143.1	5.765	24.81	.1880	-2	.6308	-2
11.10	.1171	-3	.3003	.3900	-1	11.06	.1010	-2	879.0	2.401252	105.02	5.169	.3858	143.6	5.766	24.90	.1864	-2	.6286	-2
11.12	.1157	-3	.2978	.3886	-1	11.08	.1002	-2	886.6	2.401420	105.06	5.159	.3858	144.1	5.767	24.99	.1848	-2	.6263	-2
11.14	.1143	-3	.2952	.3873	-1	11.10	.9932	-2	894.2	2.401587	105.11	5.150	.3857	144.6	5.768	25.08	.1832	-2	.6241	-2
11.16	.1130	-3	.2927	.3860	-1	11.12	.9847	-2	901.9	2.401754	105.16	5.141	.3857	145.1	5.768	25.16	.1817	-2	.6218	-2
11.18	.1116	-3	.2902	.3846	-1	11.14	.9765	-2	909.6	2.401919	105.20	5.132	.3857	145.7	5.769	25.25	.1801	-2	.6197	-2
11.20	.1103	-3	.2877	.3833	-1	11.16	.9683	-2	917.4	2.402084	105.24	5.123	.3856	146.2	5.770	25.33	.1786	-2	.6174	-2
11.22	.1090	-3	.2852	.3820	-1	11.18	.9602	-2	925.2	2.402248	105.28	5.113	.3856	146.7	5.771	25.42	.1771	-2	.6152	-2
11.24	.1077	-3	.2828	.3807	-1	11.20	.9521	-2	933.1	2.402412	105.33	5.104	.3856	147.2	5.772	25.51	.1756	-2	.6131	-2
11.26	.1064	-3	.2804	.3794	-1	11.22	.9440	-2	941.1	2.402574	105.37	5.095	.3856	147.8	5.772	25.60	.1742	-2	.6105	-2
11.28	.1051	-3	.2780	.3781	-1	11.24	.9362	-2	949.1	2.402735	105.42	5.086	.3855	148.3	5.773	25.69	.1727	-2	.6087	-2
11.30	.1039	-3	.2756	.3768	-1	11.26	.9283	-2	957.1	2.402896	105.46	5.077	.3855	148.8	5.774	25.77	.1712	-2	.6066	-2
11.32	.1026	-3	.2733	.3755	-1	11.28	.9206	-2	965.3	2.403056	105.50	5.068	.3855	149.3	5.775	25.86	.1698	-2	.6044	-2
11.34	.1014	-3	.2710	.3743	-1	11.30	.9130	-2	973.5	2.403215	105.55	5.059	.3855	149.9	5.775	25.95	.1684	-2	.6023	-2
11.36	.1002	-3	.2687	.3730	-1	11.32	.9054	-2	981.6	2.403373	105.59	5.050	.3854	150.4	5.776	26.04	.1670	-2	.6002	-2
11.38	.9905	-3	.2664	.3717	-1	11.34	.8979	-2	989.9	2.403531	105.63	5.041	.3854	150.9	5.777	26.12	.1656	-2	.5981	-2
11.40	.9788	-3	.2642	.3705	-1	11.36	.8904	-2	996.3	2.403687	105.67	5.032	.3854	151.5	5.778	26.21	.1642	-2	.5959	-2
11.42	.9673	-3	.2620	.3692	-1	11.38	.8830	-2	1007	2.403843	105.71	5.024	.3854	152.0	5.779	26.30	.1629	-2	.5939	-2
11.44	.9559	-3	.2598	.3680	-1	11.40	.8757	-2	1015	2.403998	105.75	5.015	.3853	152.5	5.779	26.39	.1615	-2	.5918	-2
11.46	.9447	-3	.2576	.3668	-1	11.42	.8685	-2	1024	2.404152	105.80	5.006	.3853	153.1	5.780	26.48	.1602	-2	.5847	-2
11.48	.9337	-3	.2554	.3655	-1	11.44	.8613	-2	1032	2.404306	105.84	4.997	.3853	153.6	5.781	26.57	.1589	-2	.5817	-2
11.50	.9228	-3	.2533	.3643	-1	11.46	.8543	-2	1041	2.404459	105.88	4.989	.3853	154.1	5.781	26.66	.1575	-2	.5858	-2
11.52	.9120	-3	.2512	.3631	-1	11.48	.8472	-2	1050	2.404610	105.92	4.980	.3852	154.7	5.782	26.75	.1563	-2	.5836	-2
11.54	.9014	-3	.2491	.3619	-1	11.50	.8403	-2	1058	2.404762	105.97	4.971	.3852	155.2	5.783	26.84	.1550	-2	.5816	-2
11.56	.8909	-3	.2470	.3607	-1	11.52	.8334	-2	1067	2.404912	106.01	4.963	.3852	155.7	5.784	26.93	.1537	-2	.5797	-2
11.58	.8806	-3	.2450	.3595	-1	11.54	.8266	-2	1076	2.405062	106.05	4.954	.3852	156.3	5.784	27.02	.1525	-2	.5776	-2

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

γ=7/5

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{g}{p_1}$	$\frac{A}{A_1}$	$\frac{V}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{12}}{p_1}$	$\frac{p_1}{p_2}$
12.30	.5857 -3	.1831 -1	.3199 -1	12.26	.6202 -3	1437	2.409989	107.44	4.663	.3843	176.3	5.808	30.36	.1144 -1	.5122 -1
12.32	.5792 -3	.1816 -1	.3189 -1	12.28	.6154 -3	1448	2.410115	107.48	4.656	.3843	176.9	5.809	30.46	.1135 -1	.5105 -1
12.34	.5729 -3	.1802 -1	.3179 -1	12.30	.6107 -3	1460	2.410239	107.51	4.648	.3843	177.5	5.809	30.55	.1126 -1	.5098 -1
12.36	.5667 -3	.1788 -1	.3169 -1	12.32	.6060 -3	1471	2.410363	107.55	4.641	.3843	178.1	5.810	30.65	.1117 -1	.5072 -1
12.38	.5605 -3	.1774 -1	.3159 -1	12.34	.6013 -3	1482	2.410486	107.59	4.633	.3843	178.6	5.810	30.75	.1109 -1	.5056 -1
12.40	.5544 -3	.1760 -1	.3149 -1	12.36	.5967 -3	1494	2.410609	107.62	4.626	.3842	179.2	5.811	30.84	.1100 -1	.5039 -1
12.42	.5484 -3	.1747 -1	.3140 -1	12.38	.5921 -3	1506	2.410731	107.66	4.618	.3842	179.8	5.812	30.94	.1092 -1	.5021 -1
12.44	.5424 -3	.1733 -1	.3130 -1	12.40	.5876 -3	1517	2.410853	107.69	4.611	.3842	180.4	5.812	31.04	.1083 -1	.5007 -1
12.46	.5365 -3	.1720 -1	.3120 -1	12.42	.5831 -3	1529	2.410974	107.73	4.603	.3842	181.0	5.813	31.13	.1075 -1	.4991 -1
12.48	.5307 -3	.1706 -1	.3110 -1	12.44	.5786 -3	1541	2.411094	107.77	4.596	.3842	181.5	5.813	31.23	.1067 -1	.4975 -1
12.50	.5250 -3	.1693 -1	.3101 -1	12.46	.5742 -3	1553	2.411214	107.80	4.589	.3841	182.1	5.814	31.33	.1059 -1	.4960 -1
12.52	.5193 -3	.1680 -1	.3091 -1	12.48	.5698 -3	1565	2.411333	107.84	4.581	.3841	182.7	5.815	31.42	.1051 -1	.4944 -1
12.54	.5137 -3	.1667 -1	.3082 -1	12.50	.5655 -3	1577	2.411452	107.87	4.574	.3841	183.3	5.815	31.52	.1043 -1	.4927 -1
12.56	.5082 -3	.1654 -1	.3072 -1	12.52	.5612 -3	1589	2.411571	107.90	4.567	.3841	183.9	5.816	31.62	.1035 -1	.4912 -1
12.58	.5028 -3	.1642 -1	.3063 -1	12.54	.5570 -3	1601	2.411688	107.94	4.559	.3841	184.5	5.816	31.72	.1027 -1	.4897 -1
12.60	.4973 -3	.1629 -1	.3053 -1	12.56	.5527 -3	1614	2.411805	107.98	4.552	.3840	185.1	5.817	31.81	.1019 -1	.4881 -1
12.62	.4920 -3	.1617 -1	.3044 -1	12.58	.5486 -3	1626	2.411922	108.01	4.545	.3840	185.6	5.817	31.91	.1011 -1	.4865 -1
12.64	.4868 -3	.1604 -1	.3035 -1	12.60	.5444 -3	1639	2.412038	108.05	4.538	.3840	186.2	5.818	32.01	.1004 -1	.4850 -1
12.66	.4816 -3	.1592 -1	.3025 -1	12.62	.5403 -3	1651	2.412154	108.08	4.530	.3840	186.8	5.819	32.11	.9961 -1	.4835 -1
12.68	.4764 -3	.1580 -1	.3016 -1	12.64	.5362 -3	1664	2.412269	108.12	4.523	.3840	187.4	5.819	32.21	.9885 -1	.4820 -1
12.70	.4714 -3	.1568 -1	.3007 -1	12.66	.5322 -3	1676	2.412383	108.15	4.516	.3839	188.0	5.820	32.31	.9810 -1	.4805 -1
12.72	.4663 -3	.1556 -1	.2995 -1	12.68	.5282 -3	1689	2.412497	108.18	4.509	.3839	188.6	5.820	32.41	.9737 -1	.4790 -1
12.74	.4614 -3	.1544 -1	.2989 -1	12.70	.5242 -3	1702	2.412611	108.22	4.502	.3839	189.2	5.821	32.50	.9664 -1	.4775 -1
12.76	.4565 -3	.1532 -1	.2979 -1	12.72	.5203 -3	1715	2.412723	108.25	4.495	.3839	189.8	5.821	32.60	.9591 -1	.4760 -1
12.78	.4517 -3	.1521 -1	.2970 -1	12.74	.5164 -3	1728	2.412836	108.29	4.488	.3839	190.4	5.822	32.70	.9520 -1	.4745 -1
12.80	.4469 -3	.1509 -1	.2961 -1	12.76	.5126 -3	1741	2.412948	108.32	4.481	.3839	191.0	5.822	32.80	.9448 -1	.4730 -1
12.82	.4422 -3	.1498 -1	.2952 -1	12.78	.5087 -3	1754	2.413059	108.35	4.474	.3838	191.6	5.823	32.90	.9378 -1	.4715 -1
12.84	.4376 -3	.1487 -1	.2944 -1	12.80	.5050 -3	1767	2.413170	108.39	4.467	.3838	192.2	5.823	33.00	.9308 -1	.4701 -1
12.86	.4329 -3	.1475 -1	.2935 -1	12.82	.5012 -3	1781	2.413280	108.42	4.460	.3838	192.8	5.824	33.10	.9239 -1	.4686 -1
12.88	.4284 -3	.1464 -1	.2926 -1	12.84	.4975 -3	1794	2.413390	108.45	4.453	.3838	193.4	5.825	33.20	.9170 -1	.4672 -1
12.90	.4239 -3	.1453 -1	.2917 -1	12.86	.4938 -3	1807	2.413500	108.49	4.446	.3838	194.0	5.825	33.30	.9102 -1	.4657 -1
12.92	.4195 -3	.1442 -1	.2908 -1	12.88	.4901 -3	1821	2.413609	108.52	4.439	.3837	194.6	5.826	33.40	.9035 -1	.4643 -1
12.94	.4151 -3	.1432 -1	.2900 -1	12.90	.4865 -3	1835	2.413717	108.55	4.432	.3837	195.2	5.826	33.50	.8968 -1	.4629 -1
12.96	.4107 -3	.1421 -1	.2891 -1	12.92	.4829 -3	1848	2.413825	108.59	4.425	.3837	195.8	5.827	33.60	.8902 -1	.4614 -1
12.98	.4065 -3	.1410 -1	.2882 -1	12.94	.4794 -3	1862	2.413932	108.62	4.419	.3837	196.4	5.827	33.70	.8836 -1	.4600 -1
13.00	.4023 -1	.1400 -1	.2874 -1	12.96	.4759 -3	1876	2.414039	108.65	4.412	.3837	197.0	5.828	33.81	.8771 -1	.4586 -1
13.02	.3981 -1	.1389 -1	.2855 -1	12.98	.4723 -3	1890	2.414146	108.68	4.405	.3837	197.6	5.828	33.91	.8706 -1	.4572 -1
13.04	.3939 -1	.1379 -1	.2857 -1	13.00	.4689 -3	1904	2.414252	108.72	4.398	.3836	198.2	5.829	34.01	.8642 -1	.4559 -1
13.06	.3898 -1	.1369 -1	.2848 -1	13.02	.4655 -3	1918	2.414357	108.75	4.391	.3836	198.8	5.829	34.11	.8580 -1	.4544 -1
13.08	.3858 -1	.1359 -1	.2840 -1	13.04	.4620 -3	1933	2.414462	108.78	4.385	.3836	199.4	5.830	34.21	.8517 -1	.4530 -1
13.10	.3818 -1	.1349 -1	.2831 -1	13.06	.4586 -3	1947	2.414567	108.82	4.378	.3836	200.1	5.830	34.31	.8453 -1	.4517 -1
13.12	.3779 -1	.1339 -1	.2823 -1	13.08	.4553 -3	1961	2.414671	108.85	4.371	.3836	200.7	5.831	34.42	.8392 -1	.4503 -1
13.14	.3740 -1	.1329 -1	.2814 -1	13.10	.4520 -3	1976	2.414775	108.88	4.365	.3836	201.3	5.831	34.52	.8331 -1	.4489 -1
13.16	.3701 -1	.1319 -1	.2806 -1	13.12	.4487 -3	1990	2.414878	108.91	4.358	.3835	201.9	5.832	34.62	.8271 -1	.4475 -1
13.18	.3663 -1	.1309 -1	.2798 -1	13.14	.4454 -3	2005	2.414981	108.94	4.351	.3835	202.5	5.832	34.72	.8210 -1	.4462 -1
13.20	.3626 -1	.1300 -1	.2790 -1	13.16	.4422 -3	2020	2.415083	108.97	4.345	.3835	203.1	5.833	34.82	.8151 -1	.4448 -1
13.22	.3589 -1	.1290 -1	.2781 -1	13.18	.4390 -3	2034	2.415185	109.01	4.338	.3835	203.7	5.833	34.93	.8091 -1	.4435 -1
13.24	.3552 -1	.1281 -1	.2773 -1	13.20	.4358 -3	2049	2.415286	109.04	4.332	.3835	204.4	5.834	35.03	.8032 -1	.4422 -1
13.26	.3516 -1	.1271 -1	.2765 -1	13.22	.4327 -3	2064	2.415387	109.07	4.325	.3835	205.0	5.834	35.13	.7974 -1	.4409 -1
13.28	.3480 -1	.1262 -1	.2757 -1	13.24	.4296 -3	2079	2.415488	109.10	4.319	.3834	205.6	5.835	35.24	.7918 -1	.4395 -1
13.30	.3444 -1	.1253 -1	.2749 -1	13.26	.4264 -3	2095	2.415588	109.13	4.312	.3834	206.2	5.835	35.34	.7860 -1	.4382 -1
13.32	.3409 -1	.1244 -1	.2741 -1	13.28	.4234 -3	2110	2.415687	109.16	4.306	.3834	206.8	5.836	35.44	.7802 -1	.4369 -1
13.34	.3374 -1	.1235 -1	.2733 -1	13.30	.4203 -3	2125	2.415788	109.19	4.299	.3834	207.5	5.836	35.55	.7747 -1	.4356 -1
13.36	.3340 -1	.1226 -1	.2725 -1	13.32	.4173 -3	2141	2.415886	109.23	4.293	.3834	208.1	5.837	35.65	.7691 -1	.4342 -1
13.38	.3306 -1	.1217 -1	.2717 -1	13.34	.4143 -3	2156	2.415983	109.26	4.286	.3834	208.7	5.837	35.76	.7636 -1	.4330 -1
13.40	.3273 -1	.1208 -1	.2709 -1	13.36	.4113 -3	2172	2.4160318	109.29	4.280	.3833	209.3	5.838	35.86	.7582 -1	.4316 -1
13.42	.3240 -1	.1200 -1	.2701 -1	13.38	.4084 -3	2188	2.4161793	109.32	4.273	.3833	210.0	5.838	35.96	.7527 -1	.4304 -1
13.44	.3207 -1	.1191 -1	.2694 -1	13.40	.4055 -3	2204	2.4162763	109.35	4.267	.3833	210.6	5.838	36.07	.7474 -1	.4291 -1
13.46	.3175 -1	.1182 -1	.2686 -1	13.42	.4026 -3	2219	2.4163730	109.38	4.261	.3833	211.2	5.839	36.17	.7420 -1	.4278 -1
13.48	.3143 -1	.1174 -1	.2678 -1	13.44	.3997 -3	2236	2.4164692	109.41	4.254	.3833	211.8	5.839	36.28	.7367 -1	.4265 -1
13.50	.3111 -1	.1165 -1	.2670 -1	13.46	.3969 -3	2252	2.4165850	109.44	4.248	.3833	212.5	5.840	36.38	.7315 -1	.4253 -1
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## REPORT 1135—NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TABLE II.—SUPERSONIC FLOW—Continued

γ=7/5

<i>M</i>	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{\rho}{\rho_1}$	$\frac{A}{A_1}$	$\frac{V}{a_\infty}$	$\nu$	$\mu$	$M_1$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$T_2$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$		
14.10	.2313	-3	.9427	-1	.2453	-1	14.06	.3219	-3	2780	2.4192569	110.32	4.067	.3826	231.8	5.853	39.60
14.12	.2290	-3	.9362	-1	.2447	-1	14.08	.3197	-3	2799	2.4193409	110.35	4.061	.3826	232.4	5.853	39.71
14.14	.2264	-3	.9297	-1	.2440	-1	14.10	.3175	-3	2818	2.4194246	110.38	4.055	.3826	233.1	5.854	39.82
14.16	.2246	-3	.9233	-1	.2433	-1	14.13	.3153	-3	2838	2.4195079	110.41	4.050	.3826	233.8	5.854	39.93
14.18	.2225	-3	.9170	-1	.2426	-1	14.15	.3132	-3	2857	2.4195909	110.44	4.044	.3826	234.4	5.854	40.04
14.20	.2204	-3	.9108	-1	.2420	-1	14.17	.3111	-3	2877	2.4196735	110.46	4.038	.3826	235.1	5.855	40.15
14.22	.2183	-3	.9045	-1	.2413	-1	14.19	.3089	-3	2897	2.4197555	110.49	4.033	.3827	235.7	5.855	40.26
14.24	.2162	-3	.8983	-1	.2406	-1	14.21	.3068	-3	2916	2.4198378	110.52	4.027	.3827	236.4	5.856	40.37
14.26	.2141	-3	.8922	-1	.2400	-1	14.23	.3048	-3	2936	2.4199194	110.54	4.021	.3827	237.1	5.856	40.48
14.28	.2121	-3	.8861	-1	.2393	-1	14.25	.3027	-3	2956	2.4200007	110.57	4.016	.3827	237.7	5.856	40.60
14.30	.2100	-3	.8800	-1	.2387	-1	14.27	.3006	-3	2977	2.4200816	110.60	4.010	.3827	238.4	5.857	40.71
14.32	.2080	-3	.8740	-1	.2380	-1	14.29	.2986	-3	2987	2.4201622	110.63	4.004	.3827	239.1	5.857	40.82
14.34	.2061	-3	.8682	-1	.2374	-1	14.31	.2967	-3	3017	2.4202425	110.65	3.999	.3827	239.7	5.858	40.93
14.36	.2041	-3	.8623	-1	.2367	-1	14.33	.2946	-3	3038	2.4203225	110.68	3.993	.3827	240.4	5.858	41.04
14.38	.2022	-3	.8565	-1	.2361	-1	14.35	.2927	-3	3058	2.4204021	110.71	3.988	.3826	241.1	5.858	41.15
14.40	.2003	-3	.8506	-1	.2355	-1	14.37	.2907	-3	3079	2.4204815	110.74	3.982	.3826	241.8	5.859	41.26
14.42	.1984	-3	.8449	-1	.2348	-1	14.39	.2886	-3	3100	2.4205604	110.76	3.977	.3826	242.4	5.859	41.38
14.44	.1965	-3	.8392	-1	.2342	-1	14.41	.2869	-3	3121	2.4206391	110.79	3.971	.3826	243.1	5.860	41.49
14.46	.1947	-3	.8335	-1	.2335	-1	14.43	.2849	-3	3142	2.4207175	110.81	3.966	.3826	243.8	5.860	41.60
14.48	.1929	-3	.8280	-1	.2329	-1	14.45	.2830	-3	3163	2.4207955	110.84	3.960	.3826	244.5	5.860	41.71
14.50	.1910	-3	.8224	-1	.2323	-1	14.47	.2812	-3	3184	2.4208732	110.87	3.955	.3826	245.1	5.861	41.83
14.52	.1892	-3	.8168	-1	.2317	-1	14.49	.2793	-3	3206	2.4209500	110.90	3.949	.3825	245.8	5.861	41.94
14.54	.1875	-3	.8114	-1	.2310	-1	14.51	.2774	-3	3227	2.4210277	110.92	3.944	.3825	246.5	5.861	42.05
14.56	.1857	-3	.8059	-1	.2304	-1	14.53	.2756	-3	3249	2.4211045	110.95	3.938	.3825	247.2	5.862	42.17
14.58	.1840	-3	.8003	-1	.2298	-1	14.55	.2737	-3	3271	2.4211810	110.97	3.933	.3825	247.8	5.862	42.28
14.60	.1823	-3	.7952	-1	.2292	-1	14.57	.2720	-3	3292	2.4212572	111.00	3.927	.3825	248.5	5.863	42.39
14.62	.1806	-3	.7899	-1	.2286	-1	14.59	.2702	-3	3314	2.4213330	111.03	3.922	.3825	249.2	5.863	42.51
14.64	.1789	-3	.7847	-1	.2280	-1	14.61	.2684	-3	3336	2.4214086	111.05	3.917	.3825	249.9	5.863	42.62
14.66	.1772	-3	.7794	-1	.2274	-1	14.63	.2666	-3	3359	2.4214838	111.08	3.911	.3825	250.6	5.864	42.73
14.68	.1756	-3	.7743	-1	.2268	-1	14.65	.2649	-3	3381	2.4215688	111.10	3.906	.3825	251.3	5.864	42.85
14.70	.1739	-3	.7691	-1	.2262	-1	14.67	.2631	-3	3404	2.4216335	111.13	3.901	.3824	251.9	5.864	42.96
14.72	.1723	-3	.7640	-1	.2256	-1	14.69	.2614	-3	3426	2.4217078	111.16	3.895	.3824	252.6	5.865	43.08
14.74	.1707	-3	.7590	-1	.2250	-1	14.71	.2597	-3	3449	2.4217819	111.18	3.890	.3824	253.3	5.865	43.19
14.76	.1692	-3	.7540	-1	.2244	-1	14.73	.2580	-3	3472	2.4218557	111.21	3.885	.3824	254.0	5.865	43.31
14.78	.1676	-3	.7490	-1	.2238	-1	14.75	.2563	-3	3494	2.4219292	111.23	3.880	.3824	254.7	5.866	43.42
14.80	.1660	-3	.7440	-1	.2232	-1	14.77	.2546	-3	3518	2.4220023	111.26	3.874	.3824	255.4	5.866	43.54
14.82	.1645	-3	.7392	-1	.2226	-1	14.79	.2530	-3	3541	2.4220752	111.28	3.869	.3824	256.1	5.866	43.65
14.84	.1630	-3	.7343	-1	.2220	-1	14.81	.2513	-3	3564	2.4221479	111.31	3.864	.3824	256.8	5.867	43.77
14.86	.1615	-3	.7295	-1	.2214	-1	14.83	.2497	-3	3588	2.4222202	111.34	3.859	.3824	257.5	5.867	43.88
14.88	.1600	-3	.7247	-1	.2208	-1	14.85	.2480	-3	3611	2.4222922	111.36	3.853	.3823	258.2	5.868	43.99
14.90	.1586	-3	.7199	-1	.2203	-1	14.87	.2464	-3	3635	2.4223640	111.38	3.848	.3823	258.9	5.868	44.11
14.92	.1571	-3	.7153	-1	.2197	-1	14.89	.2449	-3	3659	2.4224355	111.41	3.843	.3823	259.5	5.868	44.23
14.94	.1557	-3	.7106	-1	.2191	-1	14.91	.2433	-3	3683	2.4225066	111.43	3.838	.3823	260.2	5.869	44.35
14.96	.1543	-3	.7059	-1	.2185	-1	14.93	.2417	-3	3707	2.4225776	111.46	3.833	.3823	260.9	5.869	44.46
14.98	.1529	-3	.7014	-1	.2180	-1	14.95	.2401	-3	3731	2.4226482	111.48	3.828	.3823	261.6	5.869	44.58
15.00	.1515	-3	.6968	-1	.2174	-1	14.97	.2386	-3	3755	2.4227186	111.51	3.823	.3823	262.3	5.870	44.69
15.02	.1501	-3	.6923	-1	.2168	-1	14.99	.2371	-3	3779	2.4227886	111.53	3.817	.3823	263.0	5.870	44.81
15.04	.1487	-3	.6878	-1	.2163	-1	15.01	.2355	-3	3804	2.4228585	111.56	3.812	.3822	263.7	5.870	44.93
15.06	.1474	-3	.6833	-1	.2157	-1	15.03	.2340	-3	3829	2.4229280	111.59	3.807	.3822	264.4	5.871	45.05
15.08	.1461	-3	.6789	-1	.2151	-1	15.05	.2325	-3	3854	2.4229973	111.61	3.802	.3822	265.1	5.871	45.16
15.10	.1447	-3	.6745	-1	.2146	-1	15.07	.2310	-3	3879	2.4230663	111.63	3.797	.3822	265.9	5.871	45.28
15.12	.1434	-3	.6702	-1	.2140	-1	15.09	.2296	-3	3904	2.4231350	111.66	3.792	.3822	266.6	5.872	45.40
15.14	.1421	-3	.6656	-1	.2135	-1	15.11	.2281	-3	3929	2.4232035	111.68	3.787	.3822	267.3	5.872	45.52
15.16	.1409	-3	.6615	-1	.2129	-1	15.13	.2266	-3	3955	2.4232717	111.71	3.782	.3822	268.0	5.872	45.63
15.18	.1396	-3	.6573	-1	.2124	-1	15.15	.2252	-3	3980	2.4233306	111.73	3.777	.3822	268.7	5.873	45.75
15.20	.1383	-3	.6531	-1	.2118	-1	15.17	.2237	-3	4005	2.4234073	111.76	3.772	.3822	269.4	5.873	45.87
15.22	.1371	-3	.6489	-1	.2113	-1	15.19	.2223	-3	4032	2.4234747	111.78	3.767	.3821	270.1	5.873	45.99
15.24	.1359	-3	.6447	-1	.2107	-1	15.21	.2209	-3	4057	2.423419	111.80	3.762	.3821	270.8	5.874	46.11
15.26	.1347	-3	.6406	-1	.2102	-1	15.23	.2195	-3	4083	2.4236088	111.83	3.757	.3821	271.5	5.874	46.22
15.28	.1335	-3	.6365	-1	.2097	-1	15.25	.2181	-3	4110	2.4236754	111.85	3.752	.3821	272.2	5.874	46.34
15.30	.1323	-3	.6325	-1	.2091	-1	15.27	.2167	-3	4135	2.4237418	111.88	3.745	.3821	272.9	5.875	46.46
15.32	.1311	-3	.6284	-1	.2086	-1	15.29	.2152	-3	4162	2.4238079	111.90	3.743	.3821	273.7	5.875	46.58
15.34	.1299	-3	.6244	-1	.2081	-1	15.31	.2140	-3	4189	2.4238738	111.92	3.738	.3821	274.4	5.875	46.70
15.36	.1288	-3															

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPersonic FLOW—Continued

 $\gamma = 7/5$ 

M or M <sub>1</sub>	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{g}{p_1}$	$\frac{A}{A_1}$	$\frac{V}{u_1}$	$\nu$	$\mu$	M <sub>2</sub>	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{\rho_2}{\rho_1}$						
15.90	.1016	-	.5238	-	.1939	-1	15.87	.1795	-3	4990	2.4256206	112.57	3.606	.3818	.294.6	5.884	50.10	.3311	-3	.3068	-2
15.92	.1007	-	.5206	-	.1935	-1	15.89	.1787	-3	5020	2.4256797	112.59	3.601	.3818	.295.5	5.884	50.23	.3291	-3	.3060	-2
15.94	.9986	-	.5174	-	.1930	-1	15.91	.1776	-3	5051	2.4257385	112.61	3.597	.3818	.296.3	5.884	50.35	.3271	-3	.3053	-2
15.96	.9899	-	.5142	-	.1925	-1	15.93	.1765	-3	5082	2.4257971	112.63	3.592	.3818	.297.0	5.885	50.47	.3251	-3	.3045	-2
15.98	.9815	-	.5111	-	.1920	-1	15.95	.1754	-3	5113	2.4258555	112.66	3.588	.3818	.297.8	5.885	50.60	.3232	-3	.3037	-2
16.00	.9731	-	.5079	-	.1916	-1	15.97	.1744	-3	5145	2.4259137	112.68	3.583	.3817	.298.5	5.885	50.72	.3212	-3	.3030	-2
16.02	.9647	-	.5048	-	.1911	-1	15.99	.1733	-3	5176	2.4259717	112.70	3.579	.3817	.299.3	5.885	50.85	.3192	-3	.3022	-2
16.04	.9565	-	.5017	-	.1906	-1	16.01	.1723	-3	5208	2.4260295	112.72	3.574	.3817	.300.0	5.886	50.97	.3173	-3	.3015	-2
16.06	.9484	-	.4987	-	.1902	-1	16.03	.1712	-3	5239	2.4260571	112.74	3.570	.3817	.300.7	5.886	51.10	.3154	-3	.3007	-2
16.08	.9404	-	.4957	-	.1897	-1	16.05	.1702	-3	5271	2.4261441	112.76	3.566	.3817	.301.5	5.886	51.22	.3135	-3	.3000	-2
16.10	.9323	-	.4926	-	.1892	-1	16.07	.1692	-3	5304	2.4262015	112.79	3.561	.3817	.302.3	5.887	51.35	.3116	-3	.2992	-2
16.12	.9244	-	.4897	-	.1888	-1	16.09	.1681	-3	5336	2.4262585	112.81	3.557	.3817	.303.0	5.887	51.47	.3097	-3	.2985	-2
16.14	.9165	-	.4867	-	.1883	-1	16.11	.1671	-3	5369	2.4263152	112.83	3.552	.3817	.303.8	5.887	51.60	.3079	-3	.2977	-2
16.16	.9089	-	.4838	-	.1879	-1	16.13	.1661	-3	5401	2.4263717	112.85	3.548	.3817	.304.5	5.887	51.72	.3060	-3	.2970	-2
16.18	.9011	-	.4808	-	.1874	-1	16.15	.1651	-3	5434	2.4264280	112.87	3.543	.3817	.305.3	5.888	51.85	.3042	-3	.2963	-2
16.20	.8936	-	.4779	-	.1870	-1	16.17	.1642	-3	5466	2.4264841	112.89	3.539	.3817	.306.0	5.888	51.97	.3024	-3	.2955	-2
16.22	.8860	-	.4751	-	.1865	-1	16.19	.1632	-3	5499	2.4265410	112.91	3.535	.3816	.306.8	5.888	52.10	.3005	-3	.2948	-2
16.24	.8784	-	.4721	-	.1861	-1	16.21	.1622	-3	5533	2.4265958	112.94	3.530	.3816	.307.5	5.885	52.23	.2987	-3	.2941	-2
16.26	.8712	-	.4694	-	.1856	-1	16.23	.1612	-3	5566	2.4266513	112.96	3.526	.3816	.308.3	5.889	52.35	.2969	-3	.2934	-2
16.28	.8638	-	.4665	-	.1852	-1	16.25	.1603	-3	5600	2.4267066	112.98	3.522	.3816	.309.0	5.889	52.48	.2952	-3	.2926	-2
16.30	.8565	-	.4637	-	.1847	-1	16.27	.1593	-3	5634	2.4267617	113.00	3.517	.3816	.309.8	5.889	52.61	.2934	-3	.2919	-2
16.32	.8491	-	.4609	-	.1843	-1	16.29	.1584	-3	5667	2.4268166	113.02	3.513	.3816	.310.6	5.889	52.73	.2916	-3	.2912	-2
16.34	.8423	-	.4582	-	.1838	-1	16.31	.1574	-3	5701	2.4268713	113.04	3.509	.3816	.311.3	5.890	52.86	.2899	-3	.2905	-2
16.36	.8352	-	.4554	-	.1834	-1	16.33	.1563	-3	5735	2.4269258	113.06	3.504	.3816	.312.1	5.890	52.99	.2882	-3	.2908	-2
16.38	.8283	-	.4527	-	.1830	-1	16.35	.1556	-3	5770	2.4269801	113.08	3.500	.3816	.312.9	5.890	53.12	.2865	-3	.2891	-2
16.40	.8213	-	.4500	-	.1825	-1	16.37	.1546	-3	5804	2.4270342	113.11	3.496	.3816	.313.6	5.891	53.24	.2848	-3	.2884	-2
16.42	.8144	-	.4473	-	.1821	-1	16.39	.1537	-3	5839	2.4270881	113.13	3.492	.3816	.314.4	5.891	53.37	.2831	-3	.2877	-2
16.44	.8077	-	.4447	-	.1816	-1	16.41	.1528	-3	5874	2.4271415	113.15	3.487	.3815	.315.2	5.891	53.50	.2814	-3	.2870	-2
16.46	.8009	-	.4420	-	.1812	-1	16.43	.1519	-3	5910	2.4271954	113.17	3.483	.3815	.315.9	5.891	53.63	.2798	-3	.2863	-2
16.48	.7942	-	.4394	-	.1808	-1	16.45	.1510	-3	5945	2.4272487	113.19	3.479	.3815	.316.7	5.892	53.75	.2781	-3	.2856	-2
16.50	.7876	-	.4367	-	.1803	-1	16.47	.1501	-3	5980	2.4273019	113.21	3.475	.3815	.317.5	5.892	53.88	.2765	-3	.2849	-2
16.52	.7811	-	.4341	-	.1799	-1	16.49	.1492	-3	6016	2.4273548	113.23	3.470	.3815	.318.2	5.892	54.01	.2749	-3	.2842	-2
16.54	.7747	-	.4316	-	.1795	-1	16.51	.1484	-3	6051	2.4274076	113.25	3.466	.3815	.319.0	5.892	54.14	.2732	-3	.2836	-2
16.56	.7682	-	.4292	-	.1790	-1	16.53	.1474	-3	6087	2.4274601	113.27	3.462	.3815	.319.8	5.893	54.27	.2716	-3	.2826	-2
16.58	.7611	-	.4265	-	.1786	-1	16.55	.1466	-3	6123	2.4275126	113.29	3.458	.3815	.320.6	5.893	54.40	.2700	-3	.2822	-2
16.60	.7556	-	.4240	-	.1782	-1	16.57	.1457	-3	6160	2.4275641	113.31	3.454	.3815	.321.3	5.893	54.53	.2685	-3	.2814	-2
16.62	.7493	-	.4215	-	.1778	-1	16.59	.1449	-3	6196	2.4276169	113.33	3.449	.3815	.322.1	5.893	54.66	.2669	-3	.2808	-2
16.64	.7432	-	.4190	-	.1774	-1	16.61	.1440	-3	6233	2.4276687	113.35	3.445	.3815	.322.9	5.894	54.78	.2653	-3	.2801	-2
16.66	.7372	-	.4166	-	.1770	-1	16.63	.1432	-3	6268	2.4277204	113.37	3.441	.3815	.323.7	5.894	54.91	.2636	-3	.2795	-2
16.68	.7311	-	.4141	-	.1765	-1	16.65	.1424	-3	6306	2.4277719	113.39	3.437	.3814	.324.4	5.894	55.04	.2622	-3	.2788	-2
16.70	.7250	-	.4117	-	.1761	-1	16.67	.1415	-3	6343	2.4278232	113.41	3.433	.3814	.325.2	5.894	55.17	.2607	-3	.2781	-2
16.72	.7191	-	.4093	-	.1757	-1	16.69	.1407	-3	6380	2.4278743	113.43	3.429	.3814	.326.0	5.895	55.30	.2592	-3	.2774	-2
16.74	.7132	-	.4069	-	.1753	-1	16.71	.1399	-3	6417	2.4279252	113.45	3.425	.3814	.326.8	5.895	55.43	.2577	-3	.2768	-2
16.76	.7074	-	.4045	-	.1749	-1	16.73	.1391	-3	6455	2.4279760	113.47	3.421	.3814	.327.6	5.895	55.56	.2562	-3	.2762	-2
16.78	.7016	-	.4021	-	.1745	-1	16.75	.1383	-3	6493	2.4280266	113.49	3.417	.3814	.328.3	5.895	55.69	.2547	-3	.2755	-2
16.80	.6959	-	.3988	-	.1741	-1	16.77	.1375	-3	6531	2.4280770	113.51	3.413	.3814	.329.1	5.896	55.82	.2532	-3	.2748	-2
16.82	.6902	-	.3974	-	.1737	-1	16.79	.1367	-3	6570	2.4281272	113.53	3.408	.3814	.329.9	5.896	55.96	.2517	-3	.2742	-2
16.84	.6846	-	.3951	-	.1733	-1	16.81	.1359	-3	6607	2.4281771	113.55	3.404	.3814	.330.7	5.896	56.09	.2503	-3	.2735	-2
16.86	.6790	-	.3928	-	.1729	-1	16.83	.1351	-3	6647	2.4282271	113.57	3.400	.3814	.331.5	5.896	56.22	.2488	-3	.2729	-2
16.88	.6735	-	.3905	-	.1725	-1	16.85	.1343	-3	6685	2.4282768	113.59	3.396	.3814	.332.3	5.897	56.35	.2474	-3	.2722	-2
16.90	.6680	-	.3883	-	.1721	-1	16.87	.1336	-3	6724	2.4283264	113.61	3.392	.3814	.333.1	5.897	56.48	.2460	-3	.2716	-2
16.92	.6626	-	.3860	-	.1717	-1	16.89	.1328	-3	6763	2.4283757	113.63	3.388	.3813	.333.8	5.897	56.61	.2446	-3	.2709	-2
16.94	.6572	-	.3838	-	.1713	-1	16.91	.1320	-3	6802	2.4284249	113.65	3.384	.3813	.334.6	5.897	56.74	.2432	-3	.2703	-2
16.96	.6520	-	.3816	-	.1709	-1	16.93	.1313	-3	6841	2.4284739	113.67	3.380	.3813	.335.4	5.898	56.88	.2418	-3</td		

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TABLE II.—SUPERSONIC FLOW—Continued

γ=7/5

$M$ or $M_1$	$\frac{p_2}{p_1}$	$\frac{p_3}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{l^*}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{p_3}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_{12}}{p_1}$	$\frac{p_1}{p_2}$					
17.70	.4859	.3093	-1	.1571	-1	17.67	.1066	-3	8434	2.4301741	114.36	3.239	.3811	365.3	5.906	61.86	.1962	-3	.2476	-2
17.72	.4821	.3076	-1	.1567	-1	17.69	.1060	-3	8481	2.4302172	114.38	3.235	.3810	366.2	5.906	62.00	.1951	-3	.2471	-2
17.74	.4783	.3059	-1	.1564	-1	17.71	.1054	-3	8529	2.4302601	114.40	3.231	.3810	367.0	5.906	62.14	.1941	-3	.2465	-2
17.75	.4747	.3012	-1	.1561	-1	17.73	.1048	-3	8575	2.4303029	114.42	3.228	.3810	367.8	5.906	62.28	.1930	-3	.2460	-2
17.78	.4710	.3025	-1	.1557	-1	17.75	.1042	-3	8623	2.4303155	114.44	3.224	.3810	368.7	5.907	62.41	.1919	-3	.2454	-2
17.80	.4674	.3009	-1	.1554	-1	17.77	.1037	-3	8670	2.4303880	114.45	3.221	.3810	369.5	5.907	62.55	.1909	-3	.2449	-2
17.82	.4637	.2992	-1	.1550	-1	17.79	.1031	-3	8719	2.4301304	114.47	3.217	.3810	370.3	5.907	62.69	.1896	-3	.2443	-2
17.84	.4602	.2975	-1	.1547	-1	17.81	.1025	-3	8767	2.4304726	114.49	3.213	.3810	371.1	5.907	62.83	.1886	-3	.2437	-2
17.86	.4566	.2959	-1	.1543	-1	17.83	.1020	-3	8815	2.4305147	114.51	3.210	.3810	372.0	5.907	62.97	.1878	-3	.2432	-2
17.88	.4531	.2943	-1	.1540	-1	17.85	.1014	-3	8864	2.4305566	114.52	3.206	.3810	372.8	5.908	63.11	.1867	-3	.2427	-2
17.90	.4496	.2926	-1	.1537	-1	17.87	.1009	-3	8913	2.4305984	114.54	3.203	.3810	373.7	5.908	63.25	.1857	-3	.2421	-2
17.92	.4462	.2910	-1	.1533	-1	17.89	.1003	-3	8962	2.4306401	114.56	3.199	.3810	374.5	5.908	63.39	.1847	-3	.2416	-2
17.94	.4428	.2895	-1	.1530	-1	17.91	.9976	-1	9010	2.4306816	114.58	3.195	.3810	375.3	5.908	63.53	.1837	-3	.2411	-2
17.96	.4394	.2879	-1	.1526	-1	17.93	.9921	-1	9060	2.4307230	114.59	3.192	.3810	376.2	5.908	63.67	.1827	-3	.2405	-2
17.98	.4361	.2863	-1	.1523	-1	17.95	.9868	-1	9109	2.4307642	114.61	3.188	.3810	377.0	5.909	63.80	.1817	-3	.2400	-2
18.00	.4328	.2848	-1	.1520	-1	17.97	.9815	-1	9159	2.4308053	114.63	3.185	.3810	377.8	5.909	63.94	.1807	-3	.2395	-2
18.02	.4294	.2832	-1	.1516	-1	17.99	.9760	-1	9210	2.4308463	114.65	3.181	.3809	378.7	5.909	64.08	.1797	-3	.2389	-2
18.04	.4261	.2816	-1	.1513	-1	18.01	.9707	-1	9260	2.4308872	114.66	3.178	.3809	379.5	5.909	64.23	.1788	-3	.2384	-2
18.06	.4229	.2801	-1	.1510	-1	18.03	.9655	-1	9311	2.4309279	114.68	3.174	.3809	380.4	5.909	64.37	.1778	-3	.2379	-2
18.08	.4197	.2786	-1	.1507	-1	18.05	.9602	-1	9362	2.4309685	114.70	3.171	.3809	381.2	5.910	64.51	.1768	-3	.2373	-2
18.10	.4165	.2771	-1	.1503	-1	18.07	.9552	-1	9411	2.4310039	114.72	3.167	.3809	382.1	5.910	64.65	.1759	-3	.2366	-2
18.12	.4134	.2756	-1	.1500	-1	18.09	.9500	-1	9463	2.4310492	114.73	3.164	.3809	382.9	5.910	64.79	.1749	-3	.2363	-2
18.14	.4102	.2731	-1	.1497	-1	18.11	.9448	-1	9515	2.4310894	114.75	3.160	.3809	383.7	5.910	64.93	.1740	-3	.2357	-2
18.16	.4071	.2726	-1	.1494	-1	18.13	.9398	-1	9566	2.4311295	114.77	3.157	.3809	384.6	5.910	65.07	.1731	-3	.2353	-2
18.18	.4041	.2711	-1	.1490	-1	18.15	.9349	-1	9617	2.4311691	114.78	3.153	.3809	385.4	5.911	65.21	.1721	-3	.2345	-2
18.20	.4010	.2696	-1	.1487	-1	18.17	.9297	-1	9671	2.4312092	114.80	3.150	.3809	386.3	5.911	65.35	.1712	-3	.2342	-2
18.22	.3979	.2682	-1	.1484	-1	18.19	.9247	-1	9723	2.4312488	114.82	3.146	.3809	387.1	5.911	65.49	.1703	-3	.2337	-2
18.24	.3949	.2667	-1	.1481	-1	18.21	.9198	-1	9775	2.4312884	114.83	3.143	.3809	388.0	5.911	65.64	.1694	-3	.2332	-2
18.26	.3920	.2653	-1	.1477	-1	18.23	.9145	-1	9828	2.4313278	114.85	3.139	.3809	388.8	5.911	65.75	.1685	-3	.2327	-2
18.28	.3890	.2639	-1	.1474	-1	18.25	.9099	-1	9881	2.4313671	114.87	3.136	.3809	389.7	5.912	65.92	.1676	-3	.2321	-2
18.30	.3861	.2625	-1	.1471	-1	18.27	.9052	-1	9933	2.4314062	114.89	3.133	.3809	390.5	5.912	66.06	.1667	-3	.2317	-2
18.32	.3832	.2611	-1	.1468	-1	18.29	.9003	-1	9987	2.4314452	114.90	3.129	.3809	391.4	5.912	66.20	.1656	-3	.2312	-2
18.34	.3803	.2596	-1	.1465	-1	18.31	.8954	-1	1004	2.4314841	114.92	3.126	.3808	392.3	5.912	66.35	.1649	-3	.2306	-2
18.36	.3775	.2583	-1	.1462	-1	18.33	.8907	-1	1010	2.4315229	114.94	3.122	.3808	393.1	5.912	66.49	.1640	-3	.2302	-2
18.38	.3747	.2569	-1	.1459	-1	18.35	.8861	-1	1015	2.4315616	114.95	3.119	.3808	394.0	5.913	66.63	.1632	-3	.2297	-2
18.40	.3718	.2555	-1	.1455	-1	18.37	.8812	-1	1020	2.4316001	114.97	3.115	.3808	394.8	5.913	66.78	.1623	-3	.2291	-2
18.42	.3691	.2541	-1	.1452	-1	18.39	.8765	-1	1026	2.4316385	114.99	3.112	.3808	395.7	5.913	66.92	.1614	-3	.2287	-2
18.44	.3663	.2528	-1	.1449	-1	18.41	.8719	-1	1031	2.4316768	115.00	3.109	.3808	396.5	5.913	67.06	.1606	-3	.2281	-2
18.46	.3636	.2514	-1	.1446	-1	18.43	.8673	-1	1037	2.4317149	115.02	3.105	.3808	397.4	5.913	67.21	.1597	-3	.2277	-2
18.48	.3609	.2501	-1	.1443	-1	18.45	.8628	-1	1042	2.4317530	115.04	3.102	.3808	398.3	5.913	67.35	.1589	-3	.2272	-2
18.50	.3582	.2488	-1	.1440	-1	18.47	.8582	-1	1048	2.4317909	115.05	3.099	.3808	399.1	5.914	67.49	.1580	-3	.2267	-2
18.52	.3555	.2475	-1	.1437	-1	18.49	.8536	-1	1054	2.4321827	115.07	3.095	.3808	400.0	5.914	67.64	.1572	-3	.2262	-2
18.54	.3530	.2462	-1	.1434	-1	18.51	.8492	-1	1059	2.4318661	115.08	3.092	.3808	400.9	5.914	67.78	.1564	-3	.2257	-2
18.56	.3503	.2446	-1	.1431	-1	18.53	.8446	-1	1065	2.4319039	115.10	3.089	.3808	401.7	5.914	67.93	.1555	-3	.2252	-2
18.58	.3477	.2436	-1	.1428	-1	18.55	.8403	-1	1070	2.4319413	115.12	3.085	.3808	402.6	5.914	68.07	.1547	-3	.2248	-2
18.60	.3452	.2423	-1	.1425	-1	18.57	.8359	-1	1076	2.4321978	115.13	3.082	.3808	403.5	5.915	68.21	.1539	-3	.2243	-2
18.62	.3426	.2410	-1	.1422	-1	18.59	.8315	-1	1082	2.4320159	115.15	3.079	.3808	404.3	5.915	68.36	.1531	-3	.2238	-2
18.64	.3400	.2397	-1	.1419	-1	18.61	.8270	-1	1088	2.4320529	115.17	3.075	.3808	405.2	5.915	68.50	.1523	-3	.2233	-2
18.66	.3375	.2384	-1	.1416	-1	18.63	.8226	-1	1093	2.4320899	115.18	3.072	.3807	406.1	5.915	68.65	.1515	-3	.2228	-2
18.68	.3351	.2372	-1	.1413	-1	18.65	.8185	-1	1099	2.4321267	115.20	3.069	.3807	406.9	5.915	68.79	.1507	-3	.2224	-2
18.70	.3326	.2359	-1	.1410	-1	18.67	.8142	-1	1105	2.4321635	115.21	3.065	.3807	407.8	5.915	68.94	.1499	-3	.2219	-2
18.72	.3301	.2347	-1	.1407	-1	18.69	.8099	-1	1111	2.4322001	115.23	3.062	.3807	408.7	5.916	69.09	.1491	-3	.2214	-2
18.74	.3274	.2335	-1	.1404	-1	18.71	.8058	-1	1116	2.4322366	115.25	3.059	.3807	409.6	5.916	69.23	.1484	-3	.2209	-2
18.76	.3253	.2322	-1	.1401	-1	18.73	.8015	-1	1122	2.4322729	115.26	3.056	.3807	410.4	5.916	69.38	.1476	-3	.2205	-2
18.78	.3230	.2310	-1	.1398	-1	18.75	.7974	-1	1128	2.4323092	115.28	3.052	.3807	411.3	5.916	69.52	.1468	-3	.2200	-

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 1.4$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\beta$	$\frac{q}{p_1}$	$\frac{A}{A_1}$	$\frac{V}{a_1}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t_2}}{p_{t_1}}$	$\frac{p_t}{p_2}$						
19.50	.2491	-3	.1919	-1	.1298	-1	19.47	.6630	+1	1357	2.4335424	115.83	2.940	.3805	443.5	5.922	74.85	.1221	-3	.2041	-2
19.52	.2473	-3	.1909	-1	.1295	-1	19.49	.6595	+1	1365	2.4335747	115.85	2.937	.3805	444.4	5.922	75.03	.1214	-1	.2036	-2
19.54	.2455	-3	.1900	-1	.1293	-1	19.51	.6563	+1	1371	2.4336070	115.86	2.934	.3805	445.3	5.922	75.19	.1208	-1	.2032	-2
19.56	.2438	-3	.1890	-1	.1290	-1	19.53	.6530	+1	1378	2.4336391	115.88	2.931	.3805	446.2	5.923	75.34	.1202	-3	.2025	-2
19.58	.2421	-3	.1881	-1	.1287	-1	19.55	.6497	+1	1385	2.4336712	115.89	2.928	.3805	447.1	5.923	75.49	.1196	-3	.2024	-2
19.60	.2404	-3	.1871	-1	.1285	-1	19.57	.6464	+1	1392	2.4337031	115.91	2.925	.3805	448.0	5.923	75.64	.1190	-3	.2020	-2
19.62	.2387	-3	.1862	-1	.1282	-1	19.59	.6432	+1	1399	2.4337350	115.92	2.922	.3805	448.9	5.923	75.80	.1184	-3	.2016	-2
19.64	.2371	-3	.1853	-1	.1280	-1	19.61	.6401	+1	1406	2.4337667	115.94	2.919	.3805	449.9	5.923	75.95	.1178	-3	.2012	-2
19.66	.2354	-3	.1843	-1	.1277	-1	19.63	.6369	+1	1413	2.4337984	115.95	2.916	.3805	450.8	5.923	76.10	.1173	-2	.2008	-2
19.68	.2337	-3	.1834	-1	.1275	-1	19.65	.6336	+1	1420	2.4338300	115.97	2.913	.3805	451.7	5.924	76.25	.1167	-3	.2003	-2
19.70	.2321	-3	.1825	-1	.1272	-1	19.67	.6306	+1	1427	2.4338615	115.98	2.910	.3805	452.6	5.924	76.41	.1161	-3	.2000	-2
19.72	.2305	-3	.1816	-1	.1269	-1	19.69	.6274	+1	1435	2.4338926	116.00	2.907	.3805	453.5	5.924	76.56	.1155	-3	.1995	-2
19.74	.2289	-3	.1807	-1	.1267	-1	19.72	.6243	+1	1442	2.4339241	116.01	2.904	.3805	454.5	5.924	76.71	.1149	-3	.1991	-2
19.76	.2273	-3	.1799	-1	.1264	-1	19.74	.6213	+1	1449	2.4339553	116.03	2.901	.3804	455.4	5.924	76.87	.1144	-3	.1988	-2
19.78	.2257	-3	.1788	-1	.1262	-1	19.76	.6180	+1	1456	2.4339864	116.04	2.898	.3804	456.3	5.924	77.02	.1138	-3	.1983	-2
19.80	.2241	-3	.1780	-1	.1259	-1	19.78	.6150	+1	1464	2.4340174	116.05	2.895	.3804	457.2	5.924	77.17	.1132	-3	.1979	-2
19.82	.2226	-3	.1771	-1	.1257	-1	19.80	.6120	+1	1471	2.4340483	116.07	2.892	.3804	458.1	5.925	77.33	.1127	-3	.1975	-2
19.84	.2210	-3	.1762	-1	.1254	-1	19.82	.6090	+1	1478	2.4340792	116.08	2.889	.3804	459.1	5.925	77.48	.1121	-3	.1971	-2
19.86	.2195	-3	.1753	-1	.1252	-1	19.84	.6059	+1	1486	2.4341099	116.10	2.885	.3804	460.0	5.925	77.64	.1116	-3	.1967	-2
19.88	.2179	-3	.1745	-1	.1249	-1	19.86	.6029	+1	1493	2.4341405	116.11	2.883	.3804	460.9	5.925	77.79	.1110	-3	.1963	-2
19.90	.2165	-3	.1736	-1	.1247	-1	19.88	.6001	+1	1500	2.4341711	116.13	2.880	.3804	461.9	5.925	77.95	.1105	-3	.1960	-2
19.92	.2150	-3	.1727	-1	.1244	-1	19.90	.5971	+1	1508	2.4342015	116.14	2.878	.3804	462.8	5.925	78.10	.1099	-3	.1956	-2
19.94	.2135	-3	.1719	-1	.1242	-1	19.92	.5941	+1	1515	2.4342319	116.15	2.875	.3804	463.7	5.926	78.26	.1094	-3	.1952	-2
19.96	.2120	-3	.1710	-1	.1240	-1	19.94	.5913	+1	1523	2.4342622	116.17	2.872	.3804	464.6	5.926	78.41	.1088	-3	.1948	-2
19.98	.2103	-3	.1702	-1	.1237	-1	19.96	.5883	+1	1530	2.4342924	116.18	2.869	.3804	465.6	5.926	78.57	.1083	-3	.1944	-2
20.00	.2091	-3	.1694	-1	.1235	-1	19.98	.5855	+1	1538	2.4343225	116.20	2.866	.3804	466.5	5.926	78.72	.1078	-3	.1940	-2
20.20	.1952	-3	.1612	-1	.1211	-1	20.18	.5574	+1	1615	2.4346186	116.34	2.838	.3803	470.9	5.927	80.29	.1026	-3	.1902	-2
20.40	.1823	-3	.1536	-1	.1187	-1	21.34	.5311	+1	1695	2.4349062	116.47	2.810	.3803	485.4	5.929	81.86	.9776	-4	.1865	-2
20.60	.1704	-3	.1463	-1	.1165	-1	21.58	.5062	+1	1779	2.4351853	116.61	2.782	.3802	494.9	5.931	83.46	.9319	-4	.1829	-2
20.80	.1594	-3	.1395	-1	.1143	-1	20.78	.4827	+1	1866	2.4354561	116.74	2.756	.3802	504.6	5.932	85.07	.8887	-4	.1794	-2
21.00	.1492	-3	.1331	-1	.1121	-1	20.98	.4606	+1	1956	2.4357297	116.87	2.729	.3802	514.3	5.933	86.69	.8478	-4	.1760	-2
21.20	.1397	-3	.1270	-1	.1100	-1	21.18	.4396	+1	2049	2.4359772	117.00	2.704	.3801	524.2	5.934	88.34	.8091	-4	.1727	-2
21.40	.1304	-3	.1212	-1	.1081	-1	21.38	.4197	+1	2147	2.4362265	117.12	2.678	.3801	534.1	5.935	89.99	.7725	-4	.1695	-2
21.60	.1227	-3	.1158	-1	.1060	-1	21.58	.4003	+1	2248	2.4364690	117.24	2.654	.3801	544.2	5.936	91.66	.7380	-4	.1663	-2
21.80	.1151	-3	.1105	-1	.1041	-1	21.78	.3833	+1	2353	2.4367050	117.36	2.629	.3801	554.3	5.938	93.35	.7052	-4	.1633	-2
22.00	.1081	-3	.1057	-1	.1023	-1	21.98	.3662	+1	2461	2.4369346	117.48	2.605	.3801	564.5	5.939	95.05	.6742	-4	.1604	-2
22.20	.1015	-3	.1011	-1	.1004	-1	22.18	.3502	+1	2574	2.4371581	117.60	2.582	.3801	574.8	5.940	96.77	.6447	-4	.1575	-2
22.40	.9541	-3	.9670	-1	.9867	-1	22.38	.3351	+1	2690	2.4373757	117.71	2.559	.3801	585.2	5.941	98.51	.6168	-4	.1547	-2
22.60	.8971	-3	.9253	-1	.9694	-1	22.58	.3207	+1	2811	2.4375876	117.82	2.536	.3801	595.7	5.942	100.3	.5904	-4	.1520	-2
22.80	.8439	-3	.8838	-1	.9527	-1	22.78	.3171	+1	2936	2.4377940	117.93	2.514	.3798	606.3	5.943	102.0	.5653	-4	.1493	-2
23.00	.7943	-3	.8483	-1	.9363	-2	22.98	.2941	+1	3065	2.4379951	118.04	2.492	.3798	617.0	5.944	103.8	.5414	-4	.1467	-2
23.20	.7490	-3	.8127	-1	.9204	-2	23.18	.2918	+1	3199	2.4381911	118.15	2.470	.3798	627.8	5.945	105.6	.5188	-4	.1432	-2
23.40	.7048	-3	.7789	-1	.9049	-2	23.38	.2701	+1	3334	2.4383921	118.25	2.449	.3797	638.7	5.946	107.4	.4972	-4	.1418	-2
23.60	.6644	-3	.7467	-1	.8897	-2	23.58	.2590	+1	3491	2.4385683	118.36	2.429	.3797	649.6	5.947	109.2	.4768	-4	.1394	-2
23.80	.6266	-3	.7161	-1	.8750	-2	23.78	.2485	+1	3633	2.4387499	118.46	2.408	.3797	660.7	5.948	111.1	.4573	-4	.1370	-2
24.00	.5913	-3	.6871	-1	.8676	-2	23.98	.2384	+1	3783	2.4389270	118.56	2.388	.3796	671.6	5.946	112.9	.4388	-4	.1348	-2
24.20	.5582	-3	.6594	-1	.8465	-2	24.18	.2288	+1	3912	2.4390998	118.65	2.365	.3796	683.1	5.949	114.8	.4211	-4	.1325	-2
24.40	.5272	-3	.6331	-1	.8328	-2	24.38	.2197	+1	4106	2.4392683	118.75	2.349	.3796	694.4	5.950	116.7	.4044	-4	.1304	-2
24.60	.4981	-3	.6079	-1	.8195	-2	24.58	.2110	+1	4275	2.4394328	118.85	2.331	.3796	705.9	5.951	118.6	.3884	-4	.1283	-2
24.80	.4709	-3	.5839	-1	.8064	-2	24.78	.2127	+1	4450	2.4395331	118.94	2.311	.3795	717.4	5.952	120.5	.3731	-4	.1262	-2
25.00	.4454	-3	.5611	-1	.7837	-2	21.98	.1948	+1	4631	2.4397502	119.03	2.292	.3795	729.0	5.952	122.5	.3586	-4	.1242	-2
25.20	.4214	-3	.5394	-1	.7812	-2	21.18	.1873	+1	4917	2.4399033	119.12	2.274	.3795	740.7	5.953	124.4	.3447	-4	.1222	-2
25.40	.3989	-3	.5187	-1	.7697	-2	21.38	.1801	+1	5019	2.4401058	119.21	2.256	.3795	752.5	5.954	126.4	.3315	-4	.1203	-2
25.60	.3777	-3	.4988	-1	.7572	-2															

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TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$ 

$M$ or $M_1$	$\frac{p}{p_1}$	$\frac{p}{p_1}$	$\frac{T}{T_1}$	$\theta$	$\frac{\eta}{p_1}$	$\frac{1}{A_\infty}$	$\frac{1}{a_\infty}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p_1}$	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{p_{r_2}}{p_{r_1}}$	$\frac{p_1}{p_{r_1}}$							
33.00	.6454	-	.1412	-3	.4570	-2	.32 .96	.4920	-3	1837	+2	2.4438856	121.79	1.737	.3789	1270	5.973	212.7	.9053	-3	.7129	-3
33.20	.6188	-	.1370	-3	.4516	-2	.33 .18	.4774	-3	1893	+2	2.4439529	121.84	1.726	.3788	1286	5.973	215.3	.8785	-3	.7044	-3
33.40	.5935	-	.1330	-3	.4462	-2	.33 .39	.4634	-3	1950	+2	2.4440168	121.89	1.716	.3788	1301	5.973	217.9	.8527	-3	.6969	-3
33.60	.5692	-	.1291	-3	.4409	-2	.33 .59	.4499	-3	2009	+2	2.4440835	121.94	1.706	.3788	1317	5.974	220.5	.8277	-3	.6875	-3
33.80	.5462	-	.1253	-3	.4358	-2	.33 .79	.4368	-3	2069	+2	2.4441471	121.99	1.695	.3788	1333	5.974	223.1	.8037	-3	.6796	-3
34.00	.5242	-	.1217	-3	.4307	-2	.33 .99	.4242	-3	2131	+2	2.4442095	122.04	1.685	.3788	1349	5.974	225.7	.7805	-3	.6716	-3
34.20	.5032	-	.1182	-3	.4257	-2	.34 .19	.4120	-3	2194	+2	2.4442709	122.09	1.676	.3788	1364	5.975	226.4	.7581	-3	.6638	-3
34.40	.4832	-	.1148	-3	.4206	-2	.34 .39	.4002	-3	2259	+2	2.4443312	122.14	1.666	.3788	1380	5.975	231.0	.7364	-3	.6561	-3
34.60	.4610	-	.1116	-3	.4159	-2	.34 .59	.3889	-3	2325	+2	2.4443905	122.19	1.656	.3788	1397	5.975	233.7	.7155	-3	.6486	-3
34.80	.4457	-	.1084	-3	.4112	-2	.34 .79	.3779	-3	2392	+2	2.4444488	122.24	1.647	.3788	1413	5.975	236.4	.6952	-3	.6411	-3
35.00	.4283	-	.1054	-3	.4065	-2	.34 .99	.3672	-3	2462	+2	2.4445060	122.28	1.637	.3788	1429	5.976	239.1	.6757	-3	.6336	-3
35.20	.4116	-	.1024	-3	.4019	-2	.35 .19	.3570	-3	2532	+2	2.4445623	122.33	1.628	.3787	1445	5.976	241.9	.5668	-3	.6267	-3
35.40	.3957	-	.9856	-6	.3974	-2	.35 .39	.3471	-3	2605	+2	2.4446177	122.37	1.619	.3787	1462	5.976	244.6	.6385	-3	.6197	-3
35.60	.3804	-	.9680	-6	.3830	-2	.35 .59	.3375	-3	2679	+2	2.4446721	122.42	1.610	.3787	1478	5.976	247.4	.6210	-3	.6126	-3
35.80	.3658	-	.9414	-6	.3886	-2	.35 .79	.3282	-3	2754	+2	2.4447256	122.47	1.601	.3787	1495	5.977	250.2	.6039	-3	.6059	-3
36.00	.3519	-	.9156	-6	.3843	-2	.35 .99	.3192	-3	2832	+2	2.4447783	122.51	1.592	.3787	1512	5.977	252.9	.5874	-3	.5991	-3
36.20	.3346	-	.8907	-6	.3801	-2	.36 .19	.3106	-3	2911	+2	2.4448300	122.55	1.583	.3787	1529	5.977	255.8	.5714	-3	.5925	-3
36.40	.3258	-	.8666	-6	.3760	-2	.36 .39	.3022	-3	2992	+2	2.4448810	122.60	1.574	.3787	1546	5.977	258.6	.5560	-3	.5860	-3
36.60	.3136	-	.8433	-6	.3719	-2	.36 .59	.2941	-3	3075	+2	2.4449311	122.64	1.566	.3787	1563	5.978	261.4	.5410	-3	.5797	-3
36.80	.3019	-	.8207	-6	.3679	-2	.36 .79	.2862	-3	3159	+2	2.4449803	122.68	1.557	.3787	1580	5.978	264.3	.5265	-3	.5734	-3
37.00	.2907	-	.7985	-6	.3639	-2	.36 .99	.2786	-3	3246	+2	2.4450268	122.72	1.549	.3787	1597	5.978	267.1	.5126	-3	.5671	-3
37.20	.2800	-	.7777	-6	.3600	-2	.37 .19	.2712	-3	3334	+2	2.4450765	122.77	1.540	.3787	1614	5.978	270.0	.4990	-3	.5611	-3
37.40	.2697	-	.7572	-6	.3562	-2	.37 .39	.2641	-3	3424	+2	2.4451235	122.81	1.532	.3787	1632	5.979	272.9	.4858	-3	.5551	-3
37.60	.2598	-	.7373	-6	.3524	-2	.37 .59	.2572	-3	3516	+2	2.4451697	122.85	1.524	.3787	1649	5.979	275.8	.4732	-3	.5492	-3
37.80	.2504	-	.7181	-6	.3487	-2	.37 .79	.2504	-3	3611	+2	2.4452152	122.89	1.516	.3786	1667	5.979	278.8	.4608	-3	.5434	-3
38.00	.2414	-	.6995	-6	.3451	-2	.37 .99	.2449	-3	3706	+2	2.4452599	122.93	1.508	.3786	1685	5.979	281.7	.4489	-3	.5377	-3
38.20	.2327	-	.6814	-6	.3415	-2	.38 .19	.2377	-3	3805	+2	2.4453040	122.97	1.500	.3786	1702	5.980	284.7	.4373	-3	.5321	-3
38.40	.2244	-	.6639	-6	.3379	-2	.38 .39	.2316	-3	3905	+2	2.4453474	123.00	1.492	.3786	1720	5.980	287.7	.4260	-3	.5266	-3
38.60	.2164	-	.6469	-6	.3345	-2	.38 .59	.2257	-3	4087	+2	2.4453901	123.04	1.485	.3786	1738	5.980	290.7	.4152	-3	.5212	-3
38.80	.2087	-	.6305	-6	.3310	-2	.38 .79	.2199	-3	4112	+2	2.4454321	123.08	1.477	.3786	1756	5.980	293.7	.4046	-3	.5158	-3
39.00	.2013	-	.6145	-6	.3277	-2	.38 .99	.2144	-3	4219	+2	2.4454735	123.12	1.469	.3786	1774	5.980	296.7	.3944	-3	.5105	-3
39.20	.1943	-	.5991	-6	.3243	-2	.39 .19	.2090	-3	4327	+2	2.4455143	123.16	1.462	.3786	1793	5.981	299.7	.3845	-3	.5053	-3
39.40	.1875	-	.5841	-6	.3211	-2	.39 .39	.2038	-3	4328	+2	2.4455545	123.19	1.454	.3786	1811	5.981	302.8	.3749	-3	.5002	-3
39.60	.1810	-	.5695	-6	.3178	-2	.39 .59	.1987	-3	4452	+2	2.4455940	123.23	1.447	.3786	1829	5.981	305.9	.3655	-3	.4952	-3
39.80	.1748	-	.5554	-6	.3147	-2	.39 .79	.1938	-3	4667	+2	2.4456330	123.27	1.440	.3786	1848	5.981	309.0	.3565	-3	.4902	-3
40.00	.1688	-	.5417	-6	.3115	-2	.39 .99	.1890	-3	4783	+2	2.4456714	123.30	1.433	.3786	1867	5.981	312.1	.3477	-3	.4853	-3
40.20	.1630	-	.5284	-6	.3084	-2	.40 .19	.1844	-3	4906	+2	2.4457092	123.34	1.425	.3786	1885	5.982	315.2	.3392	-3	.4805	-3
40.40	.1574	-	.5155	-6	.3054	-2	.40 .39	.1799	-3	5028	+2	2.4457464	123.37	1.418	.3786	1904	5.982	318.3	.3309	-3	.4757	-3
40.60	.1521	-	.5029	-6	.3024	-2	.40 .59	.1755	-3	5154	+2	2.4457831	123.41	1.411	.3786	1923	5.982	321.5	.3229	-3	.4710	-3
40.80	.1470	-	.4908	-6	.2975	-2	.40 .79	.1713	-3	5281	+2	2.4458193	123.44	1.404	.3785	1942	5.982	324.6	.3151	-3	.4665	-3
41.00	.1420	-	.4789	-6	.2965	-2	.40 .99	.1671	-3	5412	+2	2.4458549	123.48	1.398	.3785	1961	5.982	327.8	.3075	-3	.4619	-3
41.20	.1373	-	.4675	-6	.2937	-2	.41 .19	.1631	-3	5544	+2	2.4458901	123.51	1.391	.3785	1980	5.982	331.0	.3001	-3	.4573	-3
41.40	.1327	-	.4563	-6	.2909	-2	.41 .39	.1592	-3	5680	+2	2.4459247	123.54	1.384	.3785	2000	5.983	334.2	.2929	-3	.4531	-3
41.60	.1283	-	.4455	-6	.2881	-2	.41 .59	.1555	-3	5818	+2	2.4459588	123.58	1.377	.3785	2019	5.983	337.4	.2860	-3	.4487	-3
41.80	.1241	-	.4349	-6	.2854	-2	.41 .79	.1518	-3	5959	+2	2.4459924	123.61	1.371	.3785	2038	5.983	340.7	.2793	-3	.4444	-3
42.00	.1201	-	.4247	-6	.2827	-2	.41 .99	.1482	-3	6102	+2	2.4460256	123.64	1.364	.3785	2058	5.983	343.9	.2727	-3	.4402	-3
42.20	.1161	-	.4148	-6	.2800	-2	.42 .19	.1448	-3	6248	+2	2.4460583	123.67	1.358	.3785	2078	5.983	347.2	.2663	-3	.4360	-3
42.40	.1124	-	.4051	-6	.2774	-2	.42 .39	.1414	-3	6397	+2	2.4460905	123.71	1.351	.3785	2097	5.983	350.5	.2602	-3	.4319	-3
42.60	.1087	-	.3957	-6	.2745	-2	.42 .59	.1381	-3	6549	+2	2.4461223	123.74	1.345	.3785	2117	5.984	353.8	.2541	-3	.4279	-3
42.80	.1052	-	.3866	-6	.2722	-2	.42 .79	.1349	-3	6704	+2	2.4461536	123.77	1.339	.3785	2137	5.984	357.1	.2483	-3	.4239	-3
43.00	.1019	-	.3777	-6	.2697	-2	.42 .99	.1318	-3	6861	+2	2.4461845	123.80	1.333	.3785	2157	5.984	360.5	.2426	-3	.4200	-3
43.20	.9861	-	.3691	-6	.2672	-2	.43 .19	.1285	-3	7022	+2	2.4462150	123.83	1.326	.3785	2177	5.984	363.8	.2370	-3	.4161	-3
43.40	.9548	-	.3607	-																		

## EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Concluded

 $\gamma = 1.4$ 

$M$ or $M_1$	$\frac{p}{p_t}$	$\frac{\rho}{\rho_t}$	$\frac{T}{T_t}$	$\beta$	$\frac{q}{p_t}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$	$\nu$	$\mu$	$M_2$	$\frac{p_2}{p^1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_2}$							
55.00	.1826	—	.1106	—	.1650	—	54.99	.3868	—	2341	—	2.4474679	125.25	1.042	.3783	.3529	5.991	589.1	.7111	—	.2567	—
56.00	.1609	—	.1011	—	.1592	—	55.99	.3533	—	2562	—	2.4475394	125.34	1.023	.3783	.3659	5.991	610.7	.6499	—	.2476	—
57.00	.1422	—	.9256	—	.1537	—	56.99	.3235	—	2795	—	2.4476071	125.43	1.005	.3783	.3780	5.991	632.7	.5930	—	.2190	—
58.00	.1259	—	.8495	—	.1484	—	57.99	.2935	—	3052	—	2.4476714	125.52	.9879	.3783	.3925	5.991	655.1	.5455	—	.2304	—
59.00	.1118	—	.7791	—	.1434	—	58.99	.2723	—	3324	—	2.4477325	125.60	.9712	.3782	.4061	5.991	677.8	.5009	—	.2231	—
60.00	.9937	—	.7165	—	.1387	—	59.99	.2504	—	3615	—	2.4477905	125.68	.9550	.3782	.4200	5.992	700.9	.4603	—	.2157	—
61.00	.8852	—	.6596	—	.1342	—	60.99	.2305	—	3826	—	2.4478457	125.76	.9393	.3782	.4341	5.992	724.5	.4241	—	.2057	—
62.00	.7900	—	.6002	—	.1299	—	61.99	.2126	—	4255	—	2.4478932	125.84	.9241	.3782	.4485	5.992	748.4	.3911	—	.2020	—
63.00	.7065	—	.5615	—	.1258	—	62.99	.1963	—	4612	—	2.4479453	125.91	.9095	.3782	.4630	5.993	772.7	.3611	—	.1957	—
64.00	.6328	—	.5190	—	.1219	—	63.99	.1814	—	4990	—	2.4479961	125.95	.8953	.3782	.4779	5.993	797.4	.3335	—	.1896	—
65.00	.5678	—	.4803	—	.1182	—	64.99	.1679	—	5391	—	2.4480416	126.05	.8815	.3782	.4929	5.991	822.5	.3039	—	.1838	—
66.00	.5103	—	.4451	—	.1147	—	65.99	.1556	—	5818	—	2.4480551	126.12	.8682	.3782	.5032	5.991	847.9	.2663	—	.1783	—
67.00	.4594	—	.4129	—	.1113	—	66.99	.1444	—	6271	—	2.4481237	126.18	.8552	.3782	.5237	5.991	873.8	.2655	—	.1730	—
68.00	.4141	—	.3834	—	.1090	—	67.99	.1340	—	6754	—	2.4481665	126.24	.8426	.3782	.5395	5.994	900.1	.2466	—	.1679	—
69.00	.3740	—	.3565	—	.1049	—	68.99	.1246	—	7264	—	2.4482013	126.30	.8304	.3782	.5551	5.991	926.7	.2291	—	.1631	—
70.00	.3382	—	.3318	—	.1019	—	69.99	.1160	—	7804	—	2.4482410	126.36	.8185	.3782	.5717	5.994	953.7	.2134	—	.1585	—
71.00	.3062	—	.3091	—	.9959	—	70.99	.1051	—	8378	—	2.4482759	126.42	.8070	.3782	.5851	5.994	981.1	.1985	—	.1540	—
72.00	.2777	—	.2892	—	.9336	—	71.99	.1004	—	8944	—	2.4483093	126.48	.7958	.3782	.6014	5.994	1009	.1854	—	.1493	—
73.00	.2522	—	.2690	—	.9374	—	72.99	.9406	—	9625	—	2.4483114	126.53	.7849	.3781	.6217	5.994	1037	.1730	—	.1457	—
74.00	.2293	—	.2513	—	.9122	—	73.99	.8789	—	1030	—	2.4483722	126.59	.7742	.3781	.6389	5.995	1066	.1617	—	.1418	—
75.00	.2088	—	.2351	—	.8881	—	74.99	.8220	—	1102	—	2.4484018	126.64	.7639	.3781	.6562	5.995	1095	.1512	—	.1381	—
76.00	.1903	—	.2200	—	.8649	—	75.99	.7693	—	1177	—	2.4484302	126.69	.7539	.3781	.6759	5.995	1124	.1415	—	.1345	—
77.00	.1777	—	.2061	—	.8426	—	76.99	.7207	—	1256	—	2.4484576	126.74	.7441	.3781	.6917	5.995	1154	.1326	—	.1310	—
78.00	.1587	—	.1932	—	.8212	—	77.99	.6757	—	1340	—	2.4484838	126.78	.7345	.3781	.7095	5.995	1181	.1243	—	.1276	—
79.00	.1451	—	.1813	—	.8035	—	78.99	.6341	—	1425	—	2.4485091	126.83	.7253	.3781	.7281	5.995	1215	.1166	—	.1241	—
80.00	.1329	—	.1703	—	.7806	—	79.99	.5954	—	1521	—	2.4485335	126.88	.7162	.3781	.7467	5.995	1245	.1095	—	.1214	—
81.00	.1219	—	.1600	—	.7615	—	80.99	.5593	—	1618	—	2.4485569	126.92	.7074	.3781	.7654	5.995	1277	.1030	—	.1184	—
82.00	.1118	—	.1505	—	.7431	—	81.99	.5294	—	1720	—	2.4485795	126.96	.6947	.3781	.7845	5.995	1308	.9682	—	.1155	—
83.00	.1027	—	.1417	—	.7253	—	82.99	.4934	—	1825	—	2.4486013	127.00	.6903	.3781	.8047	5.995	1341	.9113	—	.1127	—
84.00	.9148	—	.1334	—	.7081	—	83.99	.4637	—	1940	—	2.4486223	127.05	.6821	.3781	.8232	5.995	1373	.8585	—	.1101	—
85.00	.8697	—	.1258	—	.6916	—	84.99	.4399	—	2059	—	2.4486426	127.09	.6741	.3781	.8429	5.995	1406	.8092	—	.1075	—
86.00	.8014	—	.1186	—	.6756	—	85.99	.4149	—	2182	—	2.4486622	127.12	.6662	.3781	.8621	5.996	1439	.7632	—	.1050	—
87.00	.7391	—	.1120	—	.6602	—	86.99	.3916	—	2312	—	2.4486811	127.16	.6566	.3781	.8830	5.996	1473	.7204	—	.1026	—
88.00	.6823	—	.1058	—	.6452	—	87.99	.3699	—	2407	—	2.4486994	127.20	.6511	.3781	.9035	5.995	1507	.6804	—	.1003	—
89.00	.6305	—	.9995	—	.6305	—	88.99	.3495	—	2590	—	2.4487170	127.24	.6438	.3781	.9241	5.996	1541	.6431	—	.9805	—
90.00	.5831	—	.9452	—	.6169	—	89.99	.3303	—	2739	—	2.4487341	127.27	.6366	.3781	.9450	5.996	1576	.6032	—	.9585	—
91.00	.5397	—	.8944	—	.6014	—	90.99	.3129	—	2991	—	2.4487506	127.31	.6296	.3781	.9661	5.996	1611	.5755	—	.9378	—
92.00	.5000	—	.8469	—	.5914	—	91.99	.2962	—	3057	—	2.4487666	127.34	.6228	.3781	.9757	5.997	1647	.5450	—	.9175	—
93.00	.4636	—	.8023	—	.5778	—	92.99	.2407	—	3226	—	2.4487820	127.38	.6160	.3781	.1009	5.997	1683	.5163	—	.8978	—
94.00	.4302	—	.7606	—	.5656	—	93.99	.2661	—	3403	—	2.4487970	127.41	.6095	.3781	.1031	5.997	1719	.4994	—	.8790	—
95.00	.3995	—	.7214	—	.5537	—	94.99	.2521	—	3598	—	2.4488115	127.44	.6031	.3781	.1053	5.997	1756	.4642	—	.8605	—
96.00	.3712	—	.6846	—	.5422	—	95.99	.2495	—	3781	—	2.4488255	127.47	.5969	.3781	.1075	5.997	1793	.4405	—	.8427	—
97.00	.3453	—	.6501	—	.5311	—	96.99	.2274	—	3932	—	2.4488392	127.50	.5907	.3781	.1093	5.997	1831	.4183	—	.8254	—
98.00	.3214	—	.6176	—	.5204	—	97.99	.2161	—	4191	—	2.4488524	127.53	.5847	.3781	.1121	5.997	1869	.3974	—	.8087	—
99.00	.2993	—	.5870	—	.5099	—	98.99	.2054	—	4410	—	2.4488652	127.56	.5787	.3781	.1143	5.997	1907	.3778	—	.7923	—
100.00	.2790	—	.5583	—	.4995	—	100.00	.1953	—	4637	—	2.4488776	127.59	.5730	.3781	.1167	5.997	1945	.3593	—	.7765	—

## NOTATIONS FOR TABLES I AND II

$M$  or  $M_1$  local Mach number or Mach number upstream of a normal shock wave

$\frac{p}{p_t}$  ratio of static pressure to total pressure

$\frac{\rho}{\rho_t}$  ratio of static density to total density

$\frac{T}{T_t}$  ratio of static temperature to total temperature

$\beta$   $\sqrt{M^2 - 1}$

$\frac{q}{p_t}$  ratio of dynamic pressure,  $\frac{1}{2} \rho V^2$ , to total pressure

$\frac{A}{A_*}$  ratio of local cross-sectional area of an isentropic stream tube to cross-sectional area at the point where  $M=1$

$\frac{V}{a_*}$  ratio of local speed to speed of sound at the point where  $M=1$

$\nu$  Prandtl-Meyer angle (angle through which a supersonic stream is turned to expand from  $M=1$  to  $M>1$ ), deg

$\mu$  Mach angle,  $\sin^{-1} \frac{1}{M}$ , deg

$M_2$  Mach number downstream of a normal shock wave

$\frac{p_2}{p_1}$  static pressure ratio across a normal shock wave

$\frac{\rho_2}{\rho_1}$  static density ratio across a normal shock wave

$\frac{T_2}{T_1}$  static temperature ratio across a normal shock wave

$\frac{p_{t2}}{p_{t1}}$  total pressure ratio across a normal shock wave

$\frac{p_1}{p_{t2}}$  ratio of static pressure upstream of a normal shock wave to total pressure downstream

## CHARTS

The charts that follow present numerical values of certain physical quantities that are functions of two variables and hence are cumbersome to tabulate. These charts are designed to provide accuracy to three significant figures.

Charts 1 through 8 and chart 25 are for a perfect gas. The values presented in charts 1 through 4 and chart 25 were calculated for a ratio of specific heats of 7/5. The values presented in charts 5 through 8 were taken from references 6 and 14 and are for a ratio of specific heats of 1.405.

Charts 9 through 24 provide correction factors to account for the effects of caloric imperfections on the quantities tabulated in tables I and II and plotted in charts 2, 3, and 4.

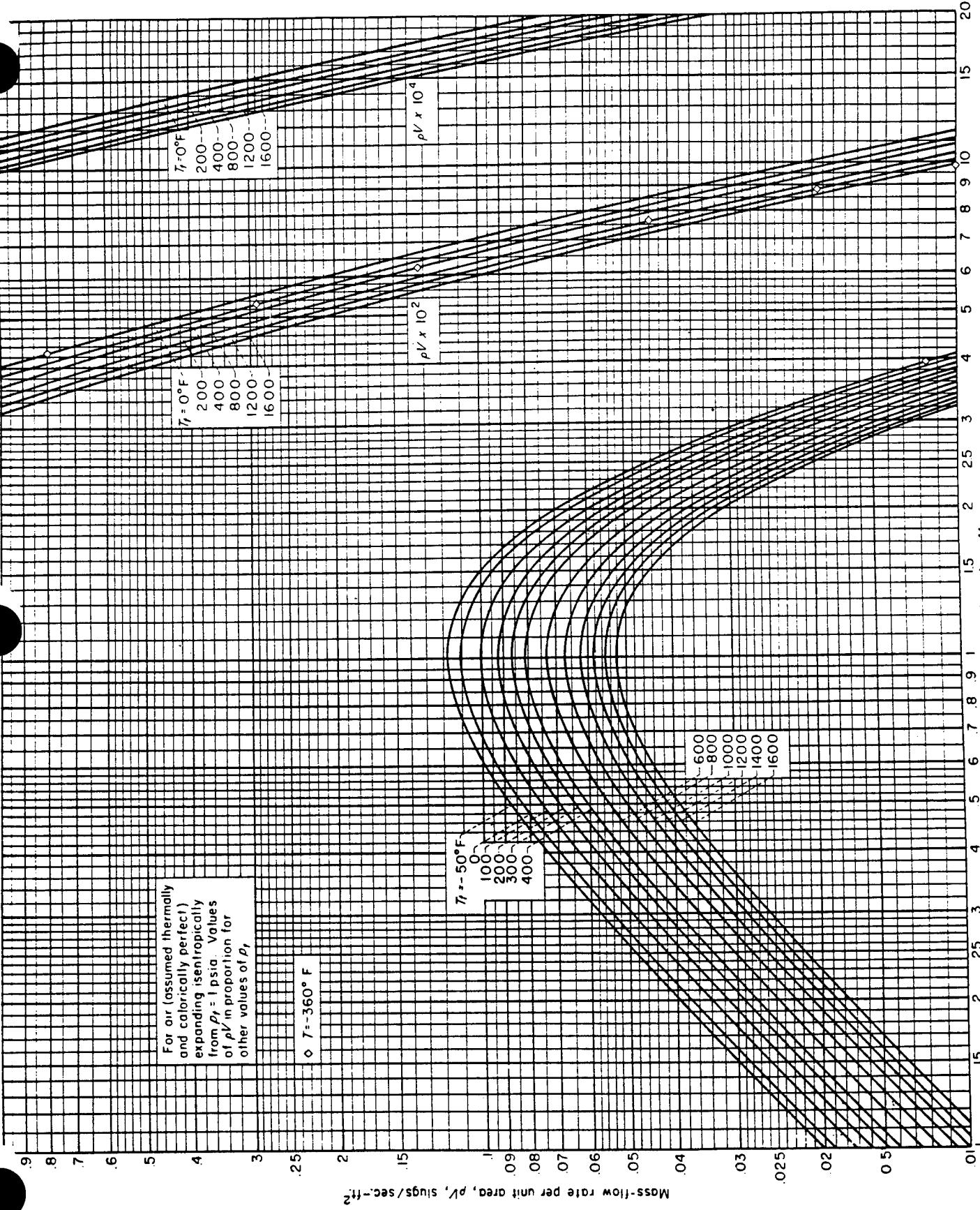
On many charts, points corresponding to static temperatures of 5000° R and 100°R (-360° F) have been indicated. These temperatures represent very approximately the limits of validity of the charts. Exact limits cannot be stated simply as they depend on pressure as well as temperature. At temperatures near 5000° R dissociation effects, which were neglected in the calculations, can be significant at high altitudes though perhaps not at sea level. At temperatures less than about 100° R, air may condense at the pressures encountered in many wind tunnels.

On the Reynolds number chart (chart 25), points corresponding to a static temperature of 180° R (-280° F) also are indicated since this is the lowest temperature for which experimental viscosity data have been obtained. At temperatures much lower than -280° F, Sutherland's equation (A2) may significantly underestimate the true viscosity.

The contents of the charts are as follows:

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CHART 1.... Variation of mass-flow rate per unit area with Mach number for various total temperatures. Perfect gas,  $\gamma$

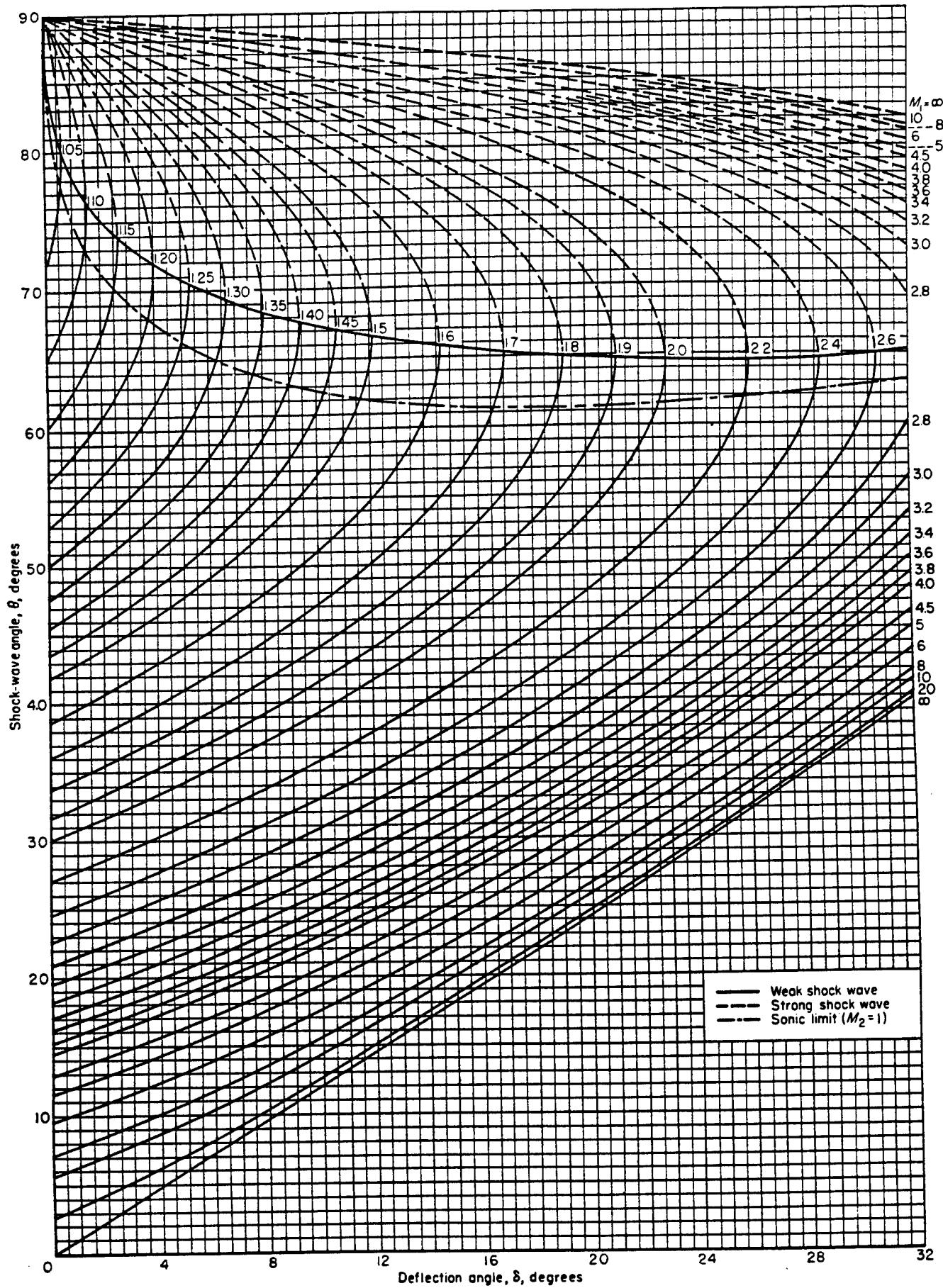


CHART 2.—Variation of shock-wave angle with flow-deflection angle for various upstream Mach numbers. Perfect gas,  $\gamma = \frac{5}{3}$ .

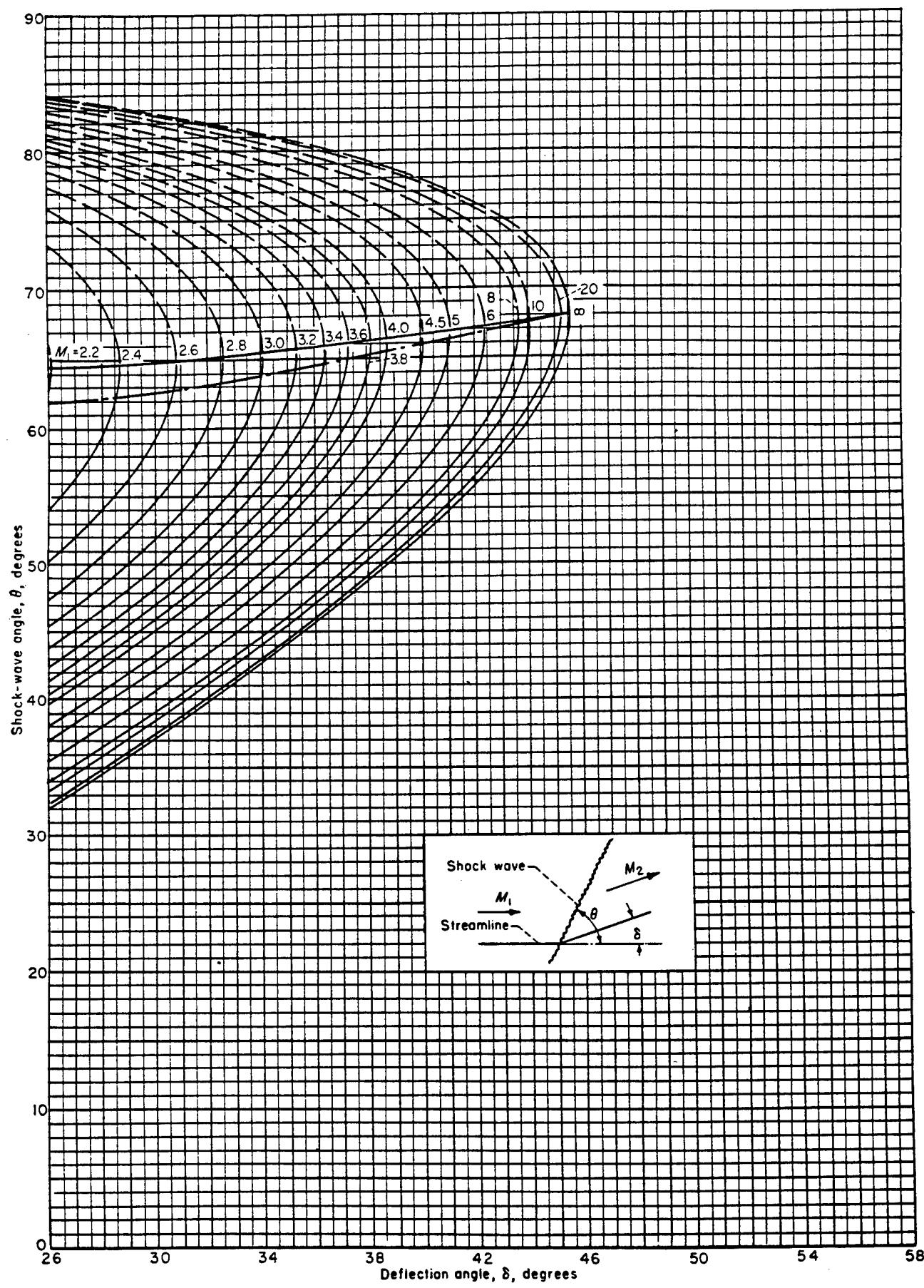


CHART 2.—Concluded

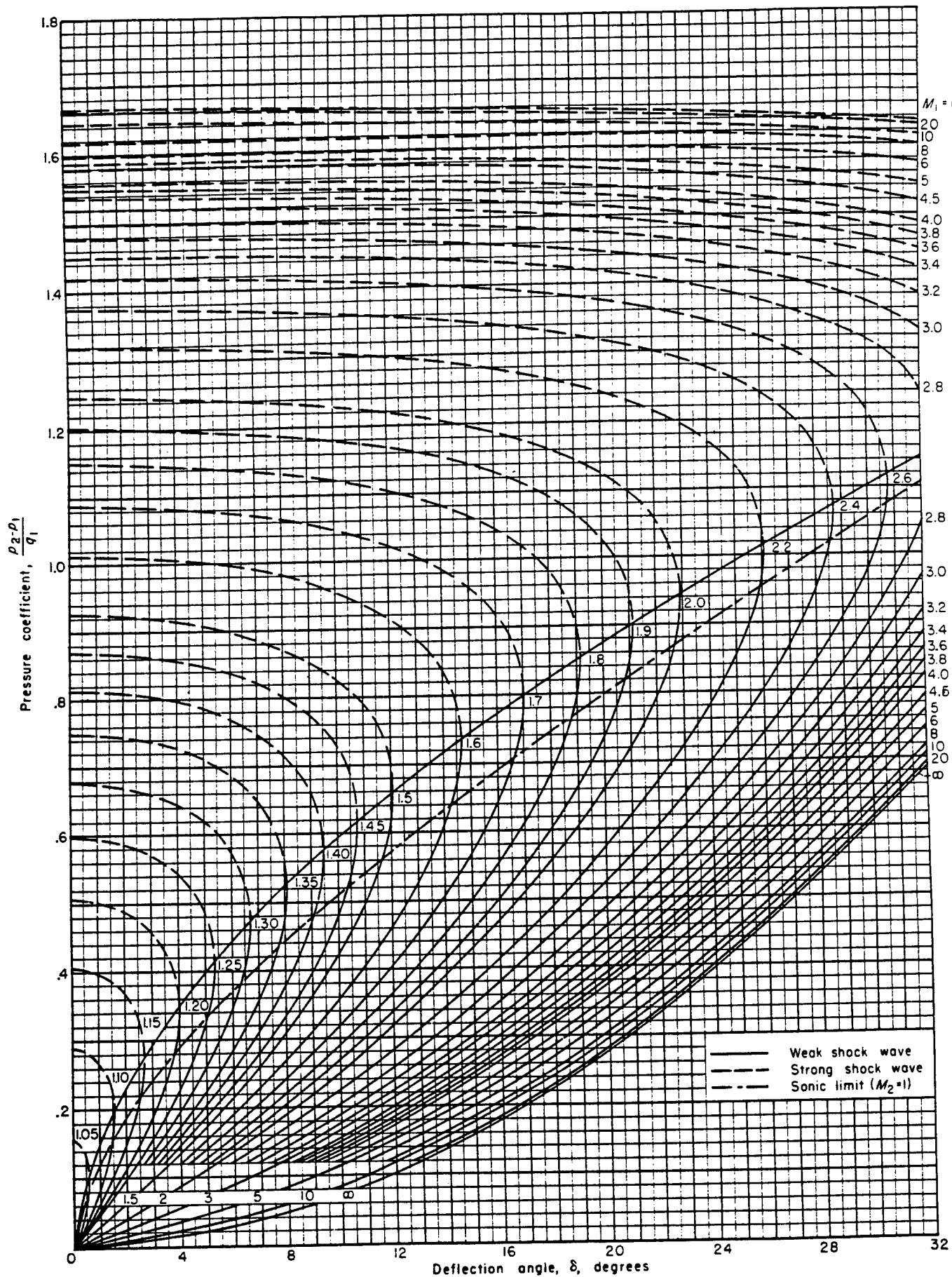


CHART 3.—Variation of pressure coefficient across shock waves with flow-deflection angle for various upstream Mach numbers. Perfect gas,  $\gamma$

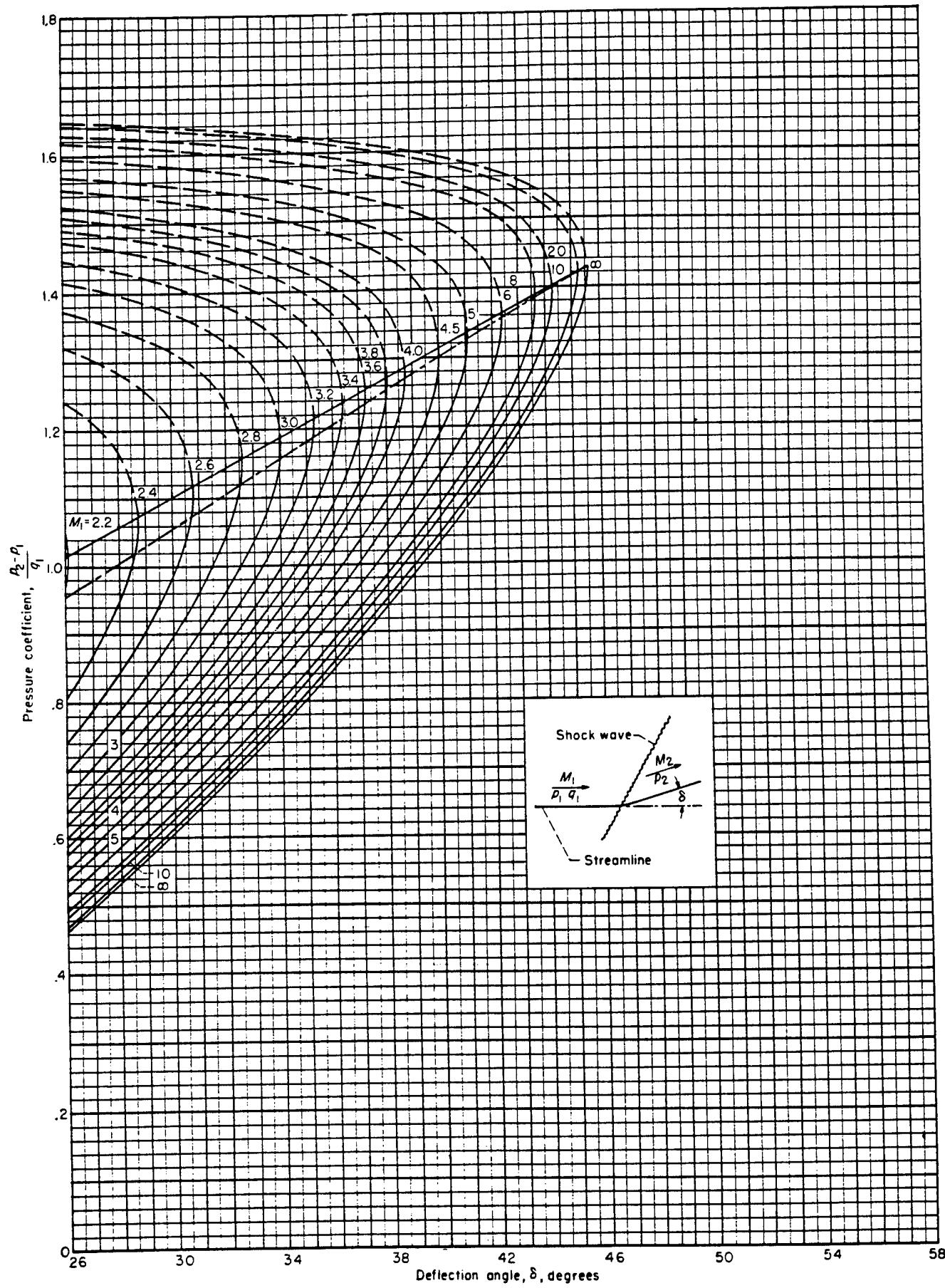


CHART 3.—Concluded

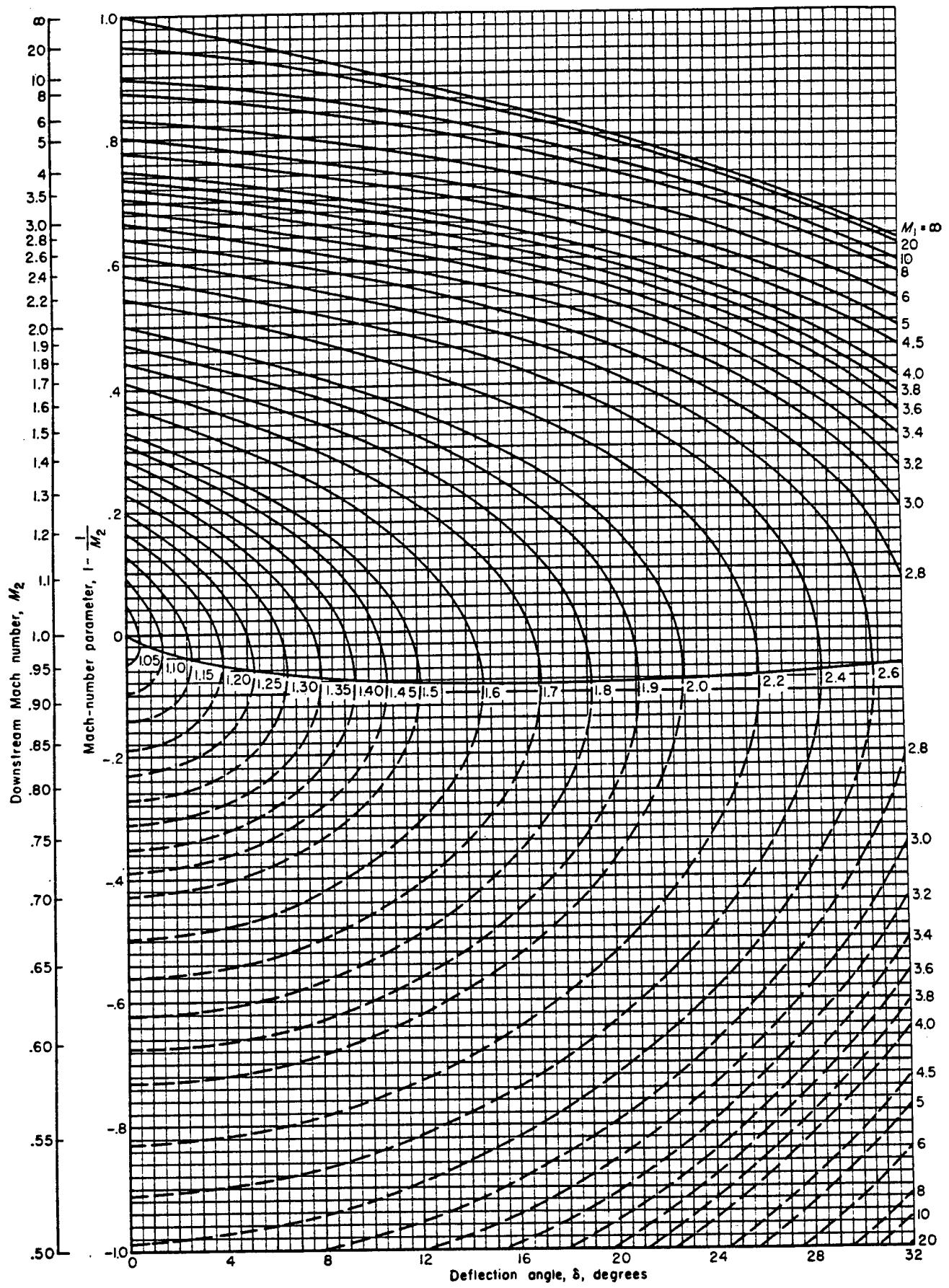
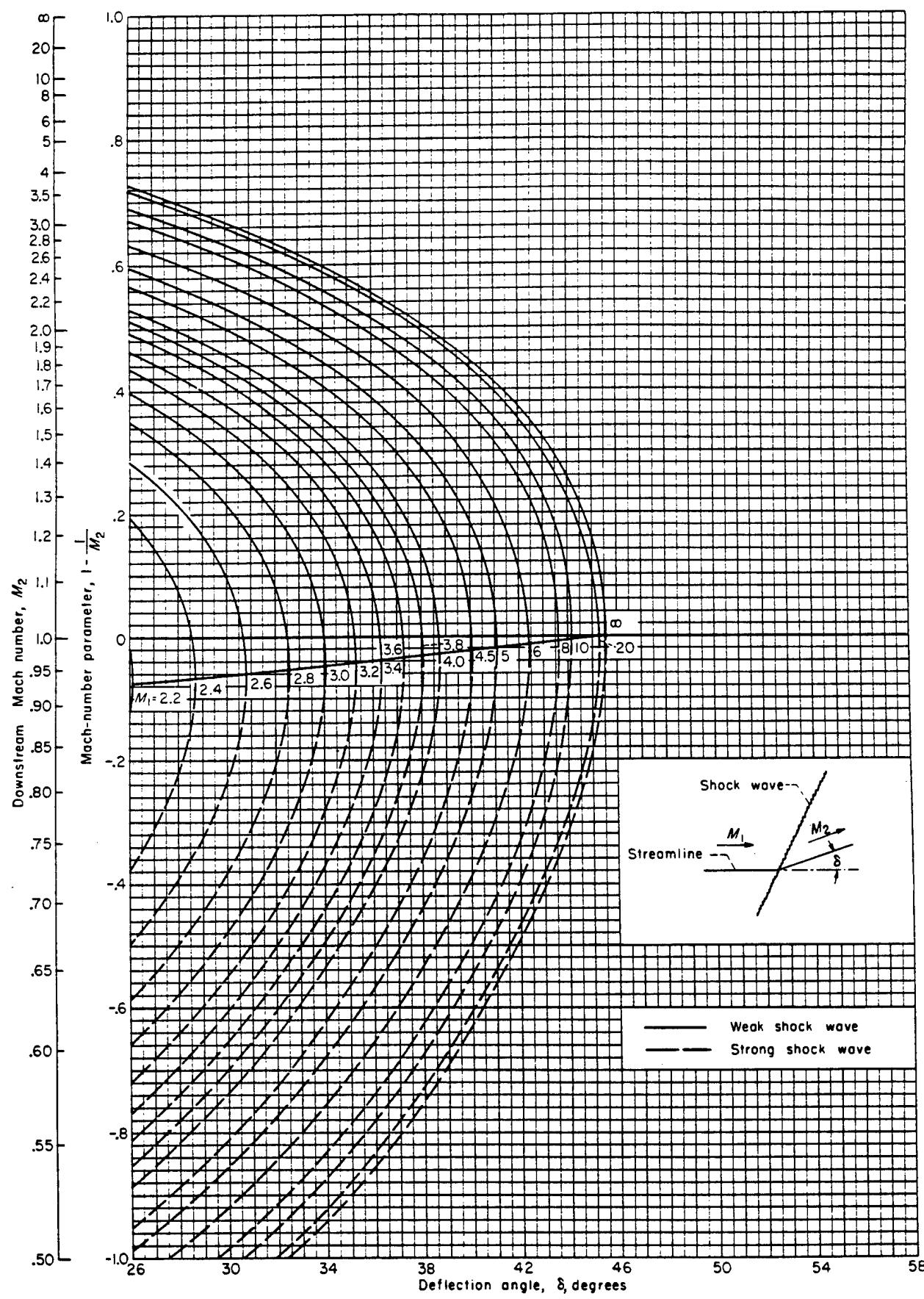


CHART 4.—Variation of Mach number downstream of a shock wave with flow-deflection angle for various upstream Mach numbers. Perfect gas,  $\gamma = 7/5$ .



**CHART 4.—Concluded**

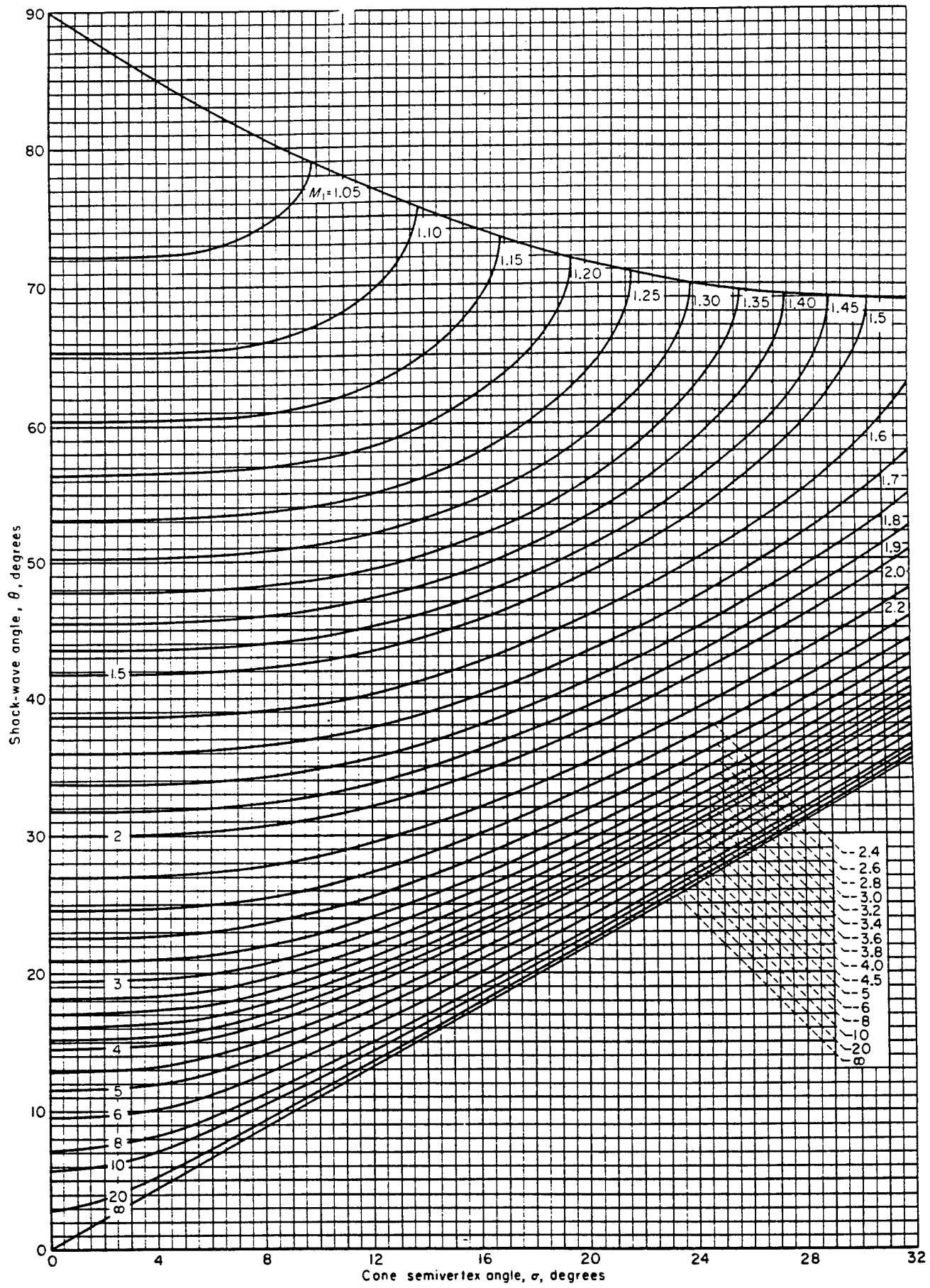


CHART 5.—Variation of shock-wave angle with cone semivertex angle for various upstream Mach numbers. Perfect gas,  $\gamma=1.405$ .

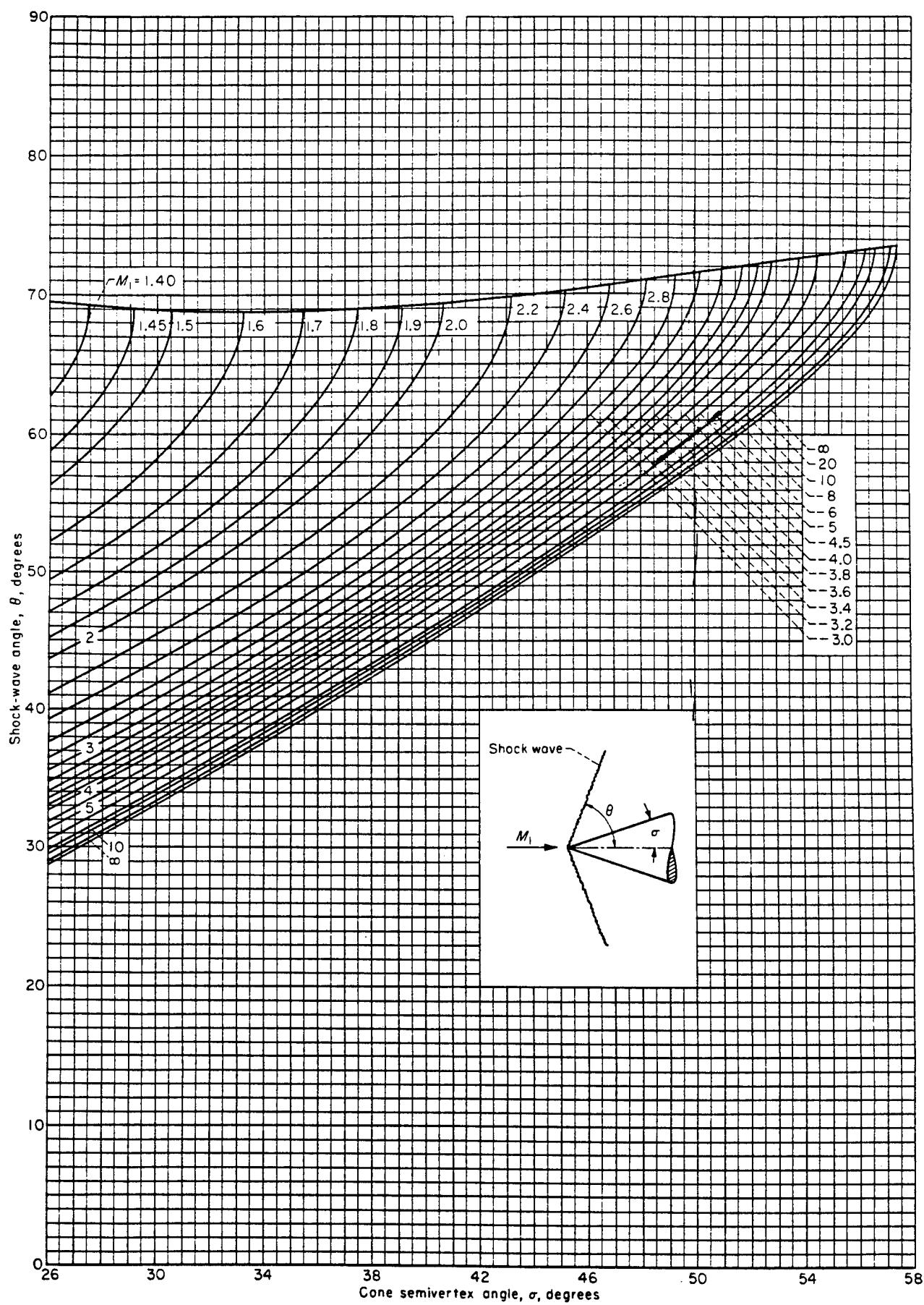


CHART 5.—Concluded

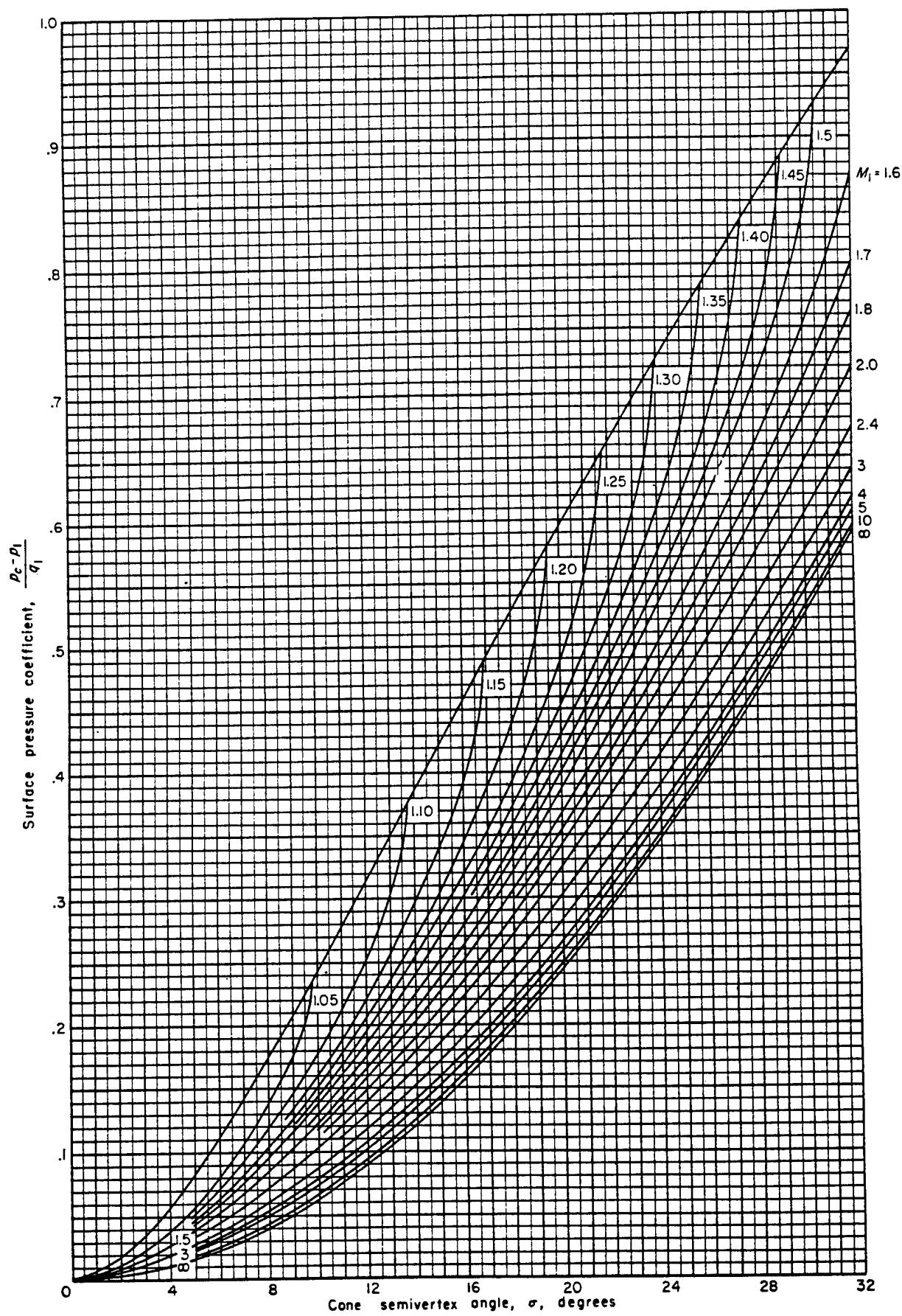


CHART 6.—Variation of surface pressure coefficient with cone semivertex angle for various upstream Mach numbers. Perfect gas,  $\gamma=1.405$ .

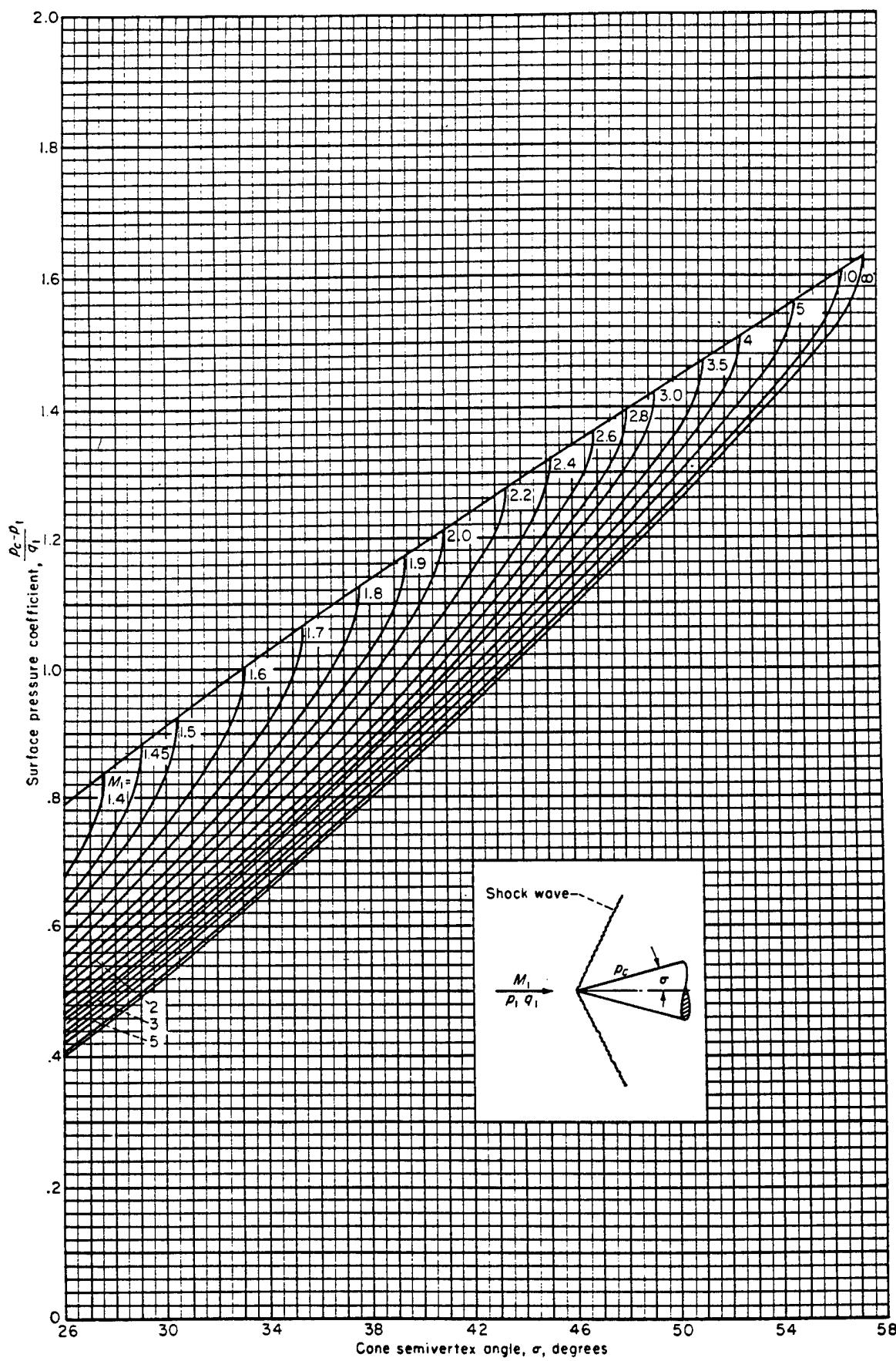


CHART 6.—Concluded

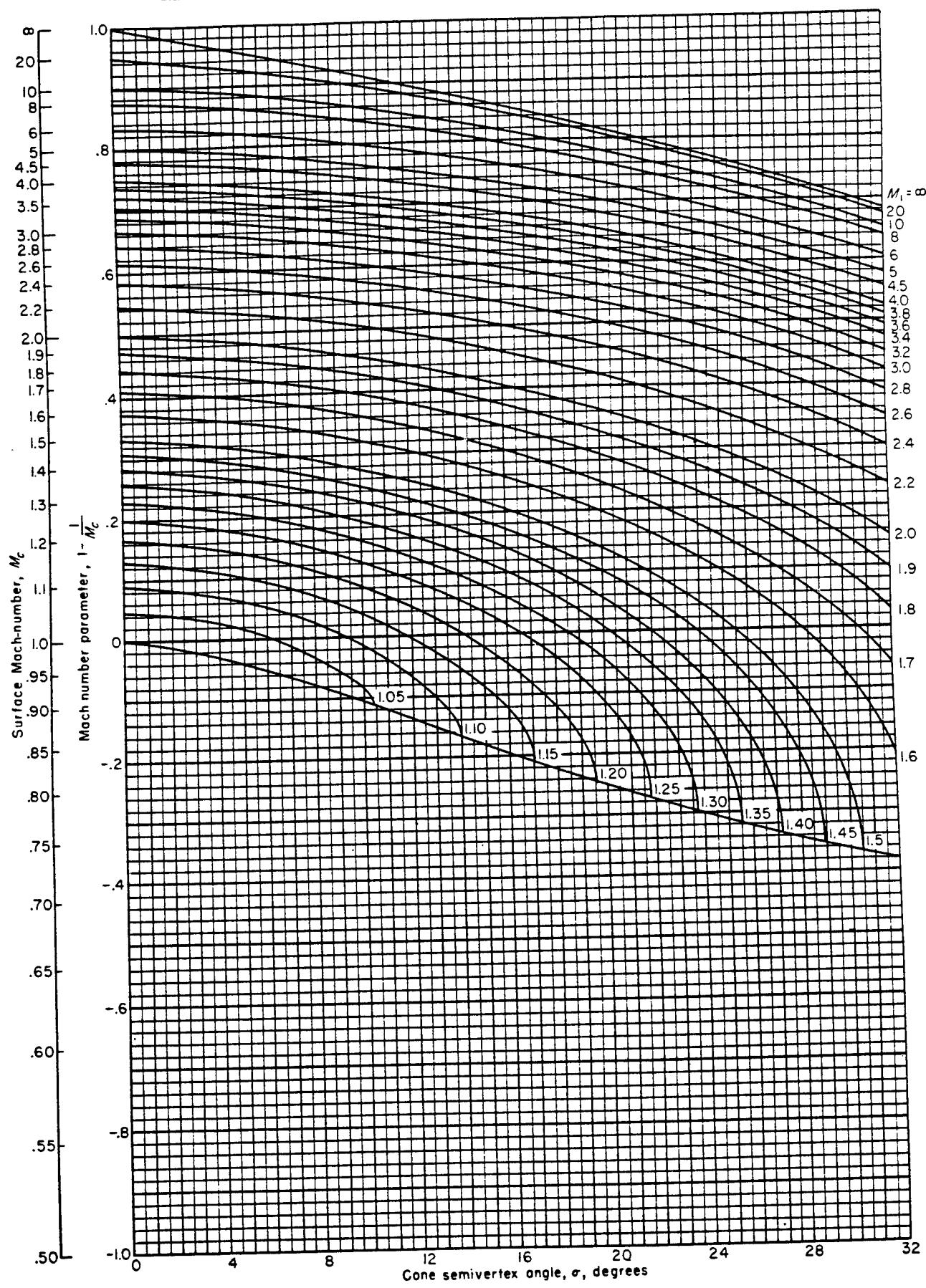


CHART 7.—Variation of Mach number at the surface of a cone with cone semivertex angle for various upstream Mach numbers. Perfect gas,  $\gamma = 1.405$ .

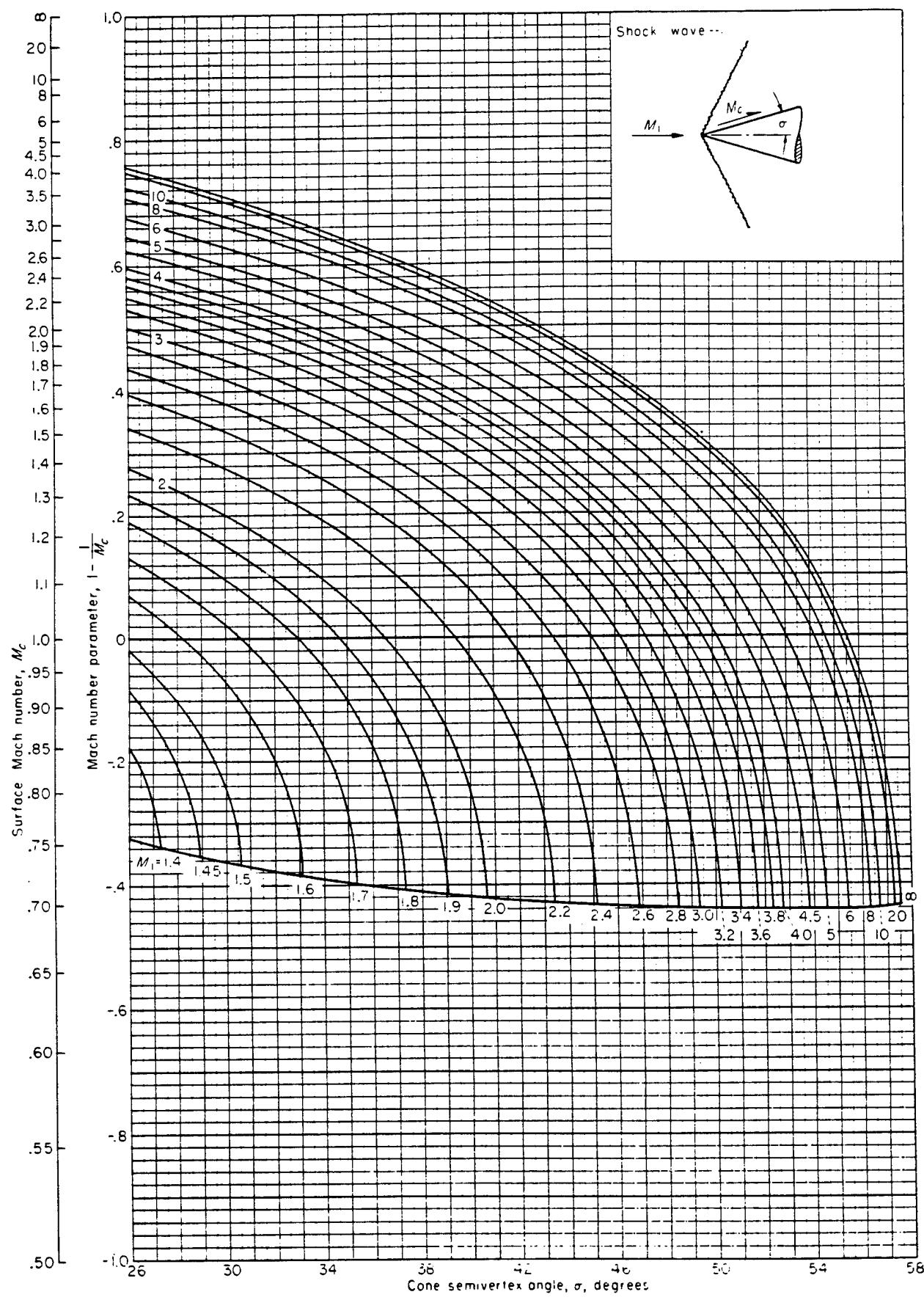


CHART 7.—Concluded

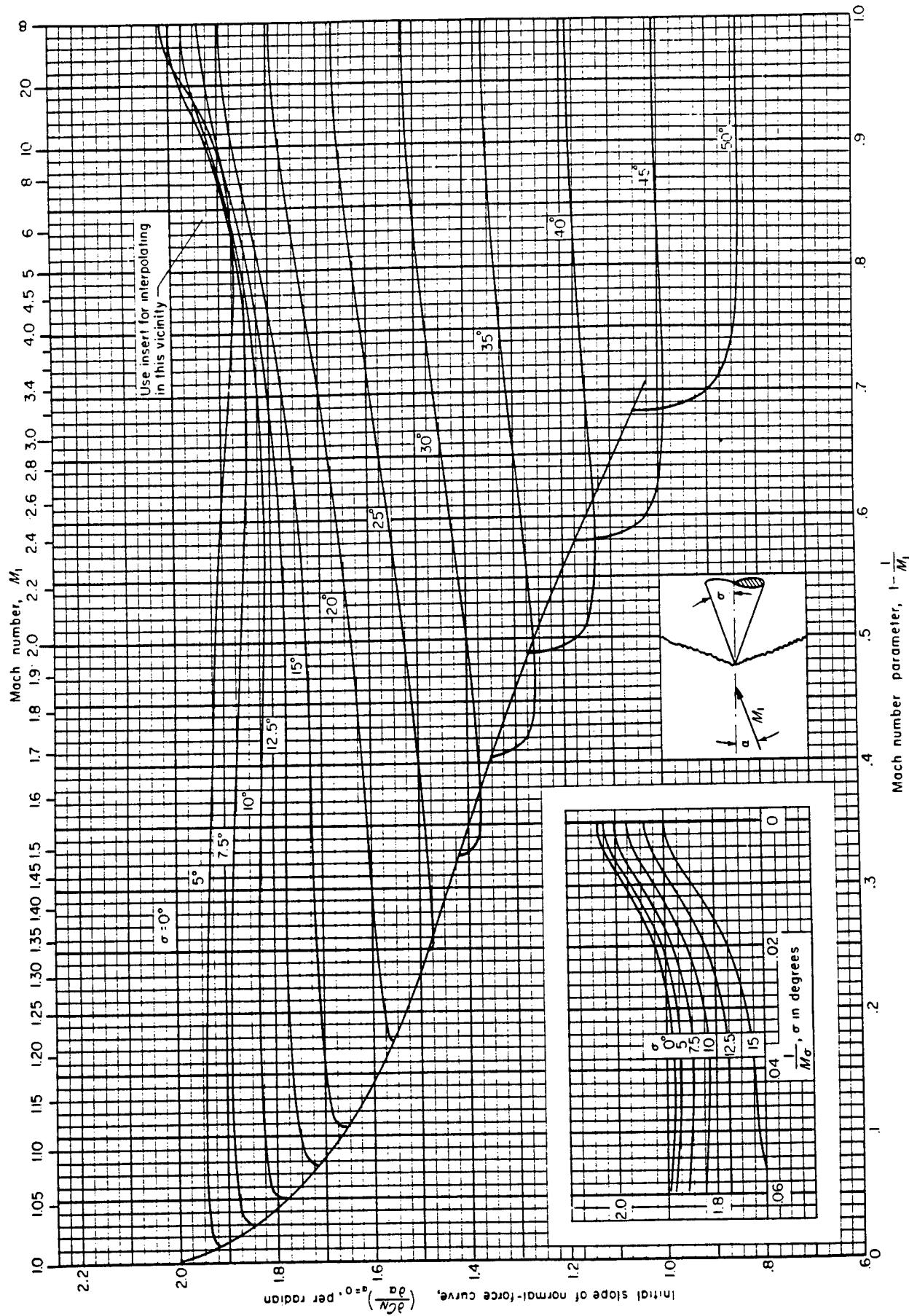


CHART 8.—Variation of the initial slope of the normal-force curve with upstream Mach number for various cone semivertex angles. Perfect gas,  
 $\gamma = 1.405$ .

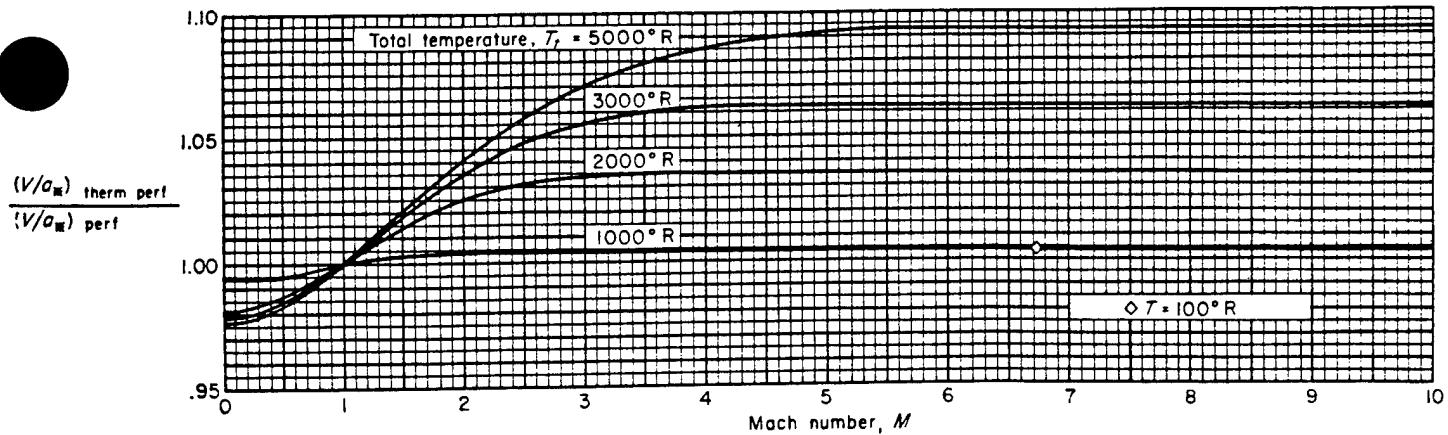
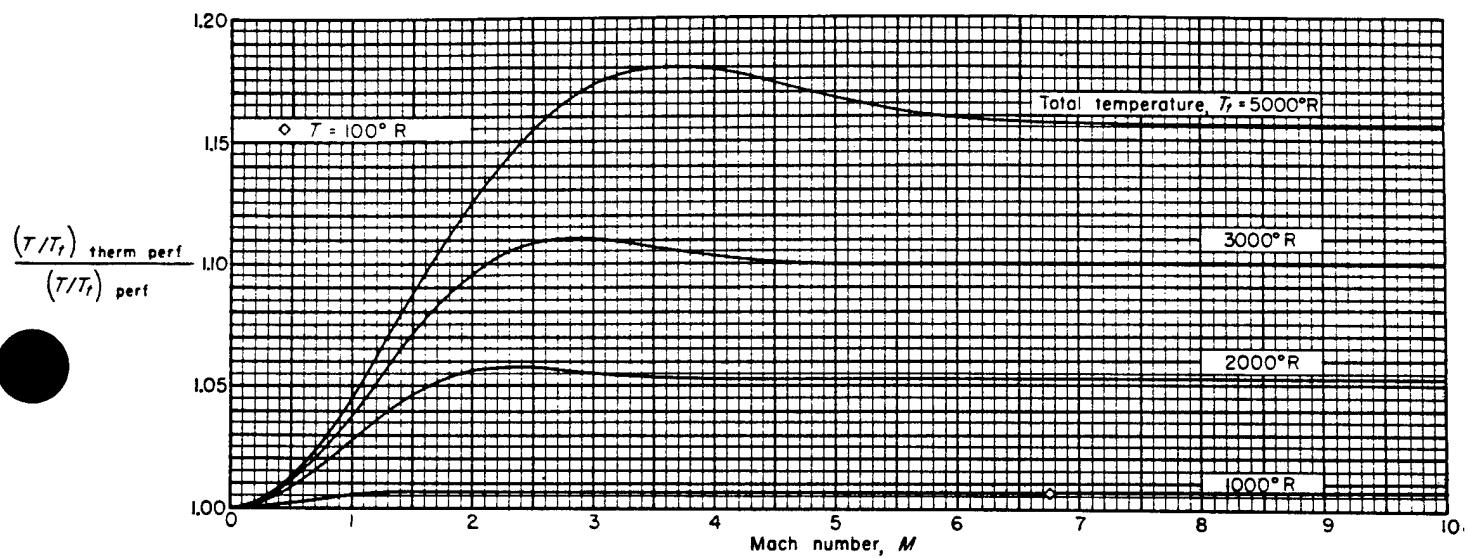
CHART 9.—Effect of caloric imperfections on the ratio of local speed to speed of sound at the point where  $M=1$ .

CHART 10.—Effect of caloric imperfections on the ratio of static temperature to total temperature.

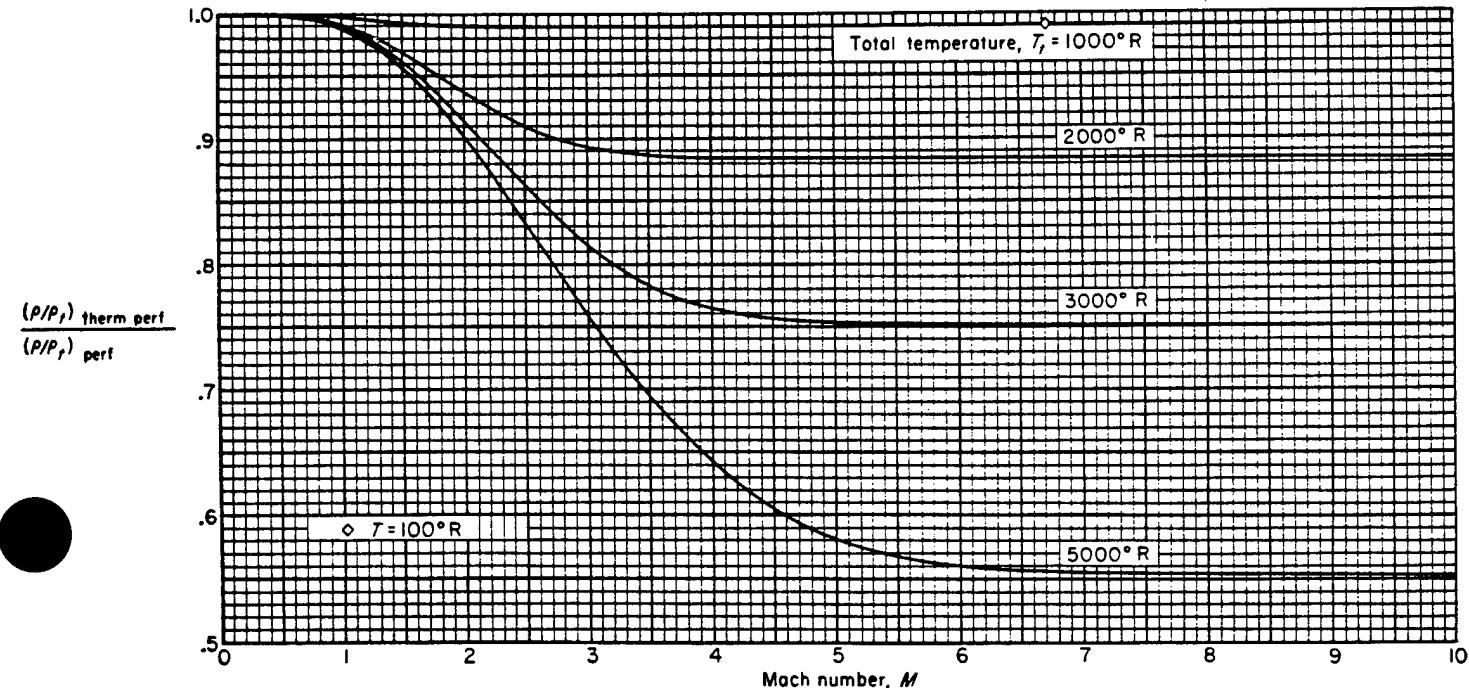


CHART 11.—Effect of caloric imperfections on the ratio of static density to total density.

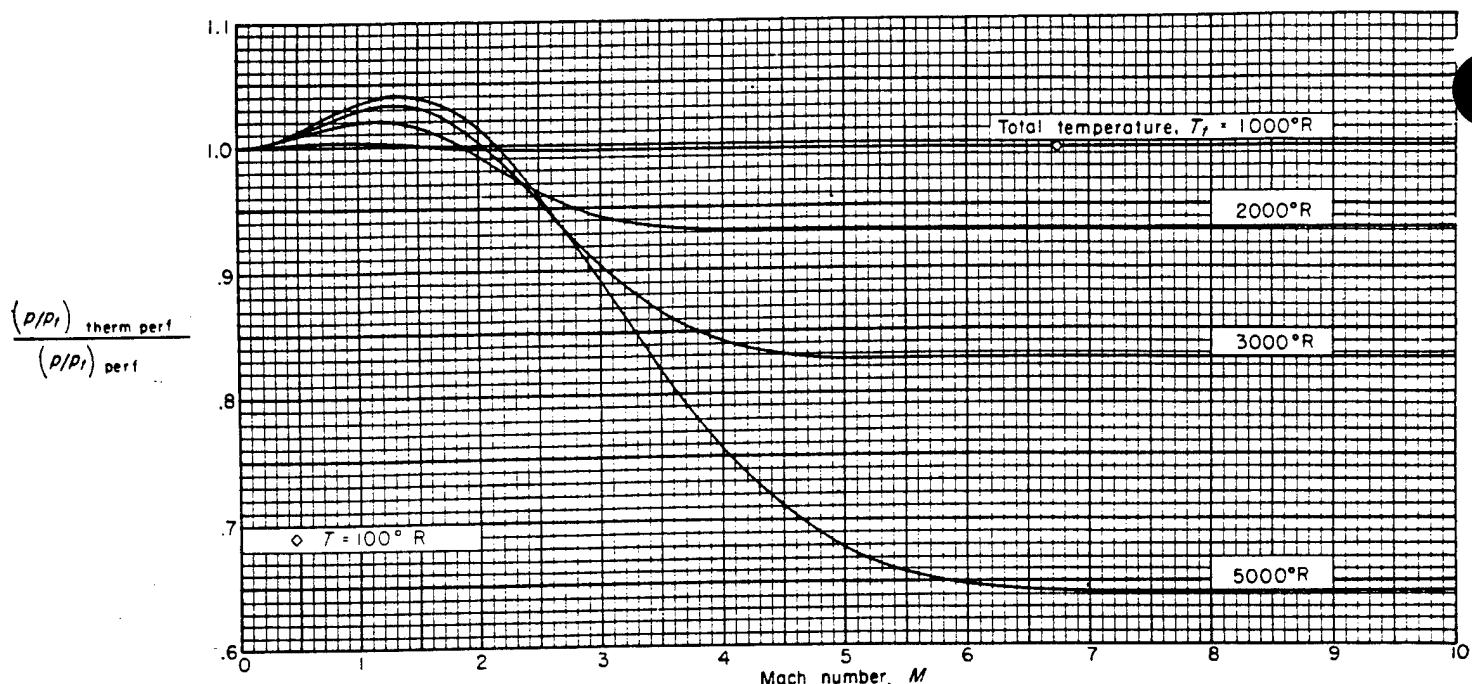


CHART 12.—Effect of calorific imperfections on the ratio of static pressure to total pressure.

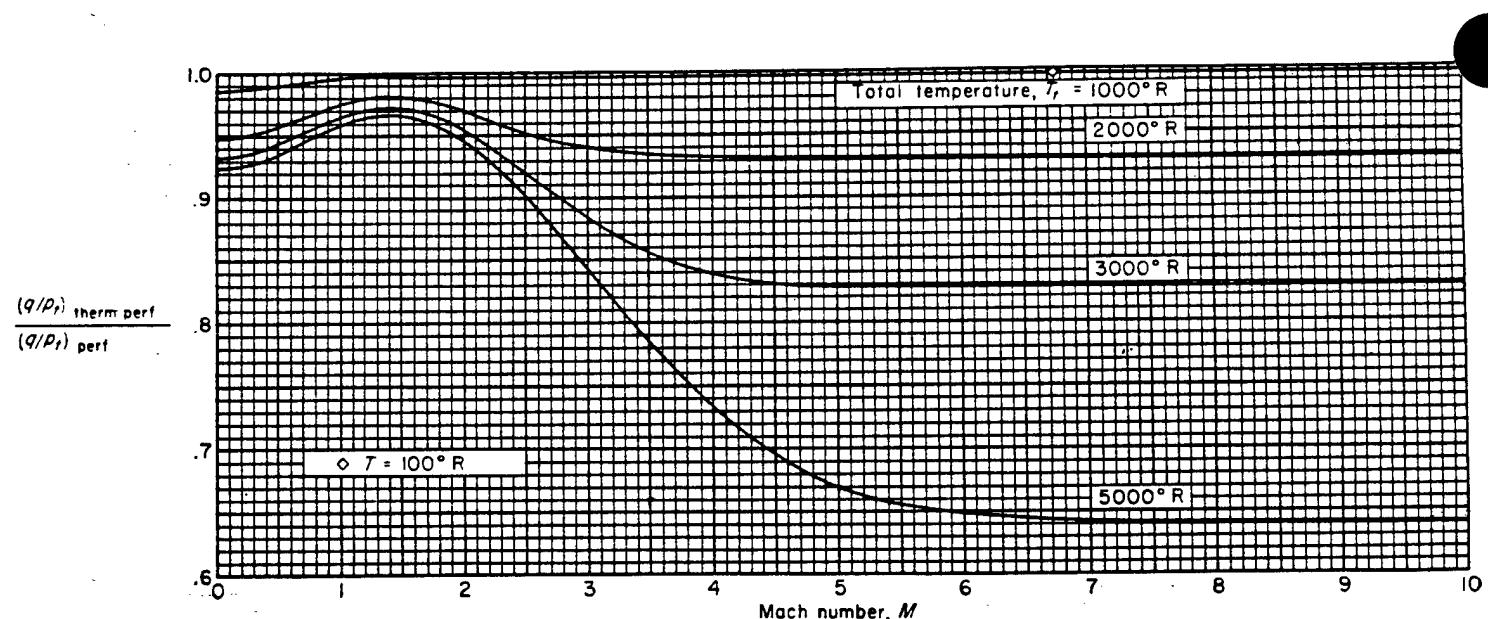


CHART 13.—Effect of calorific imperfections on the ratio of dynamic pressure to total pressure.

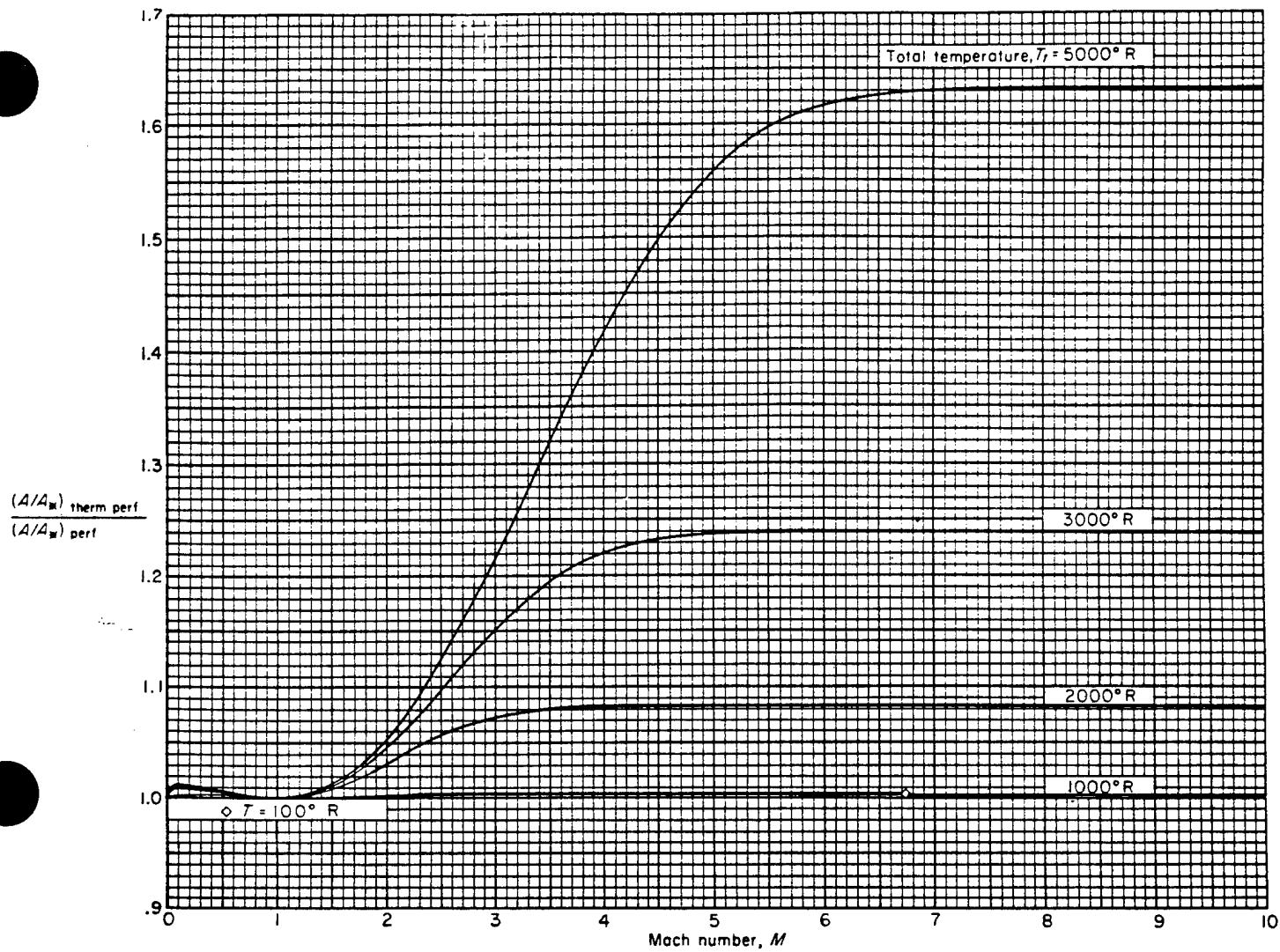


CHART 14.—Effect of caloric imperfections on the ratio of local cross-sectional area of a stream tube to the cross-sectional area at the point where  $M=1$ .

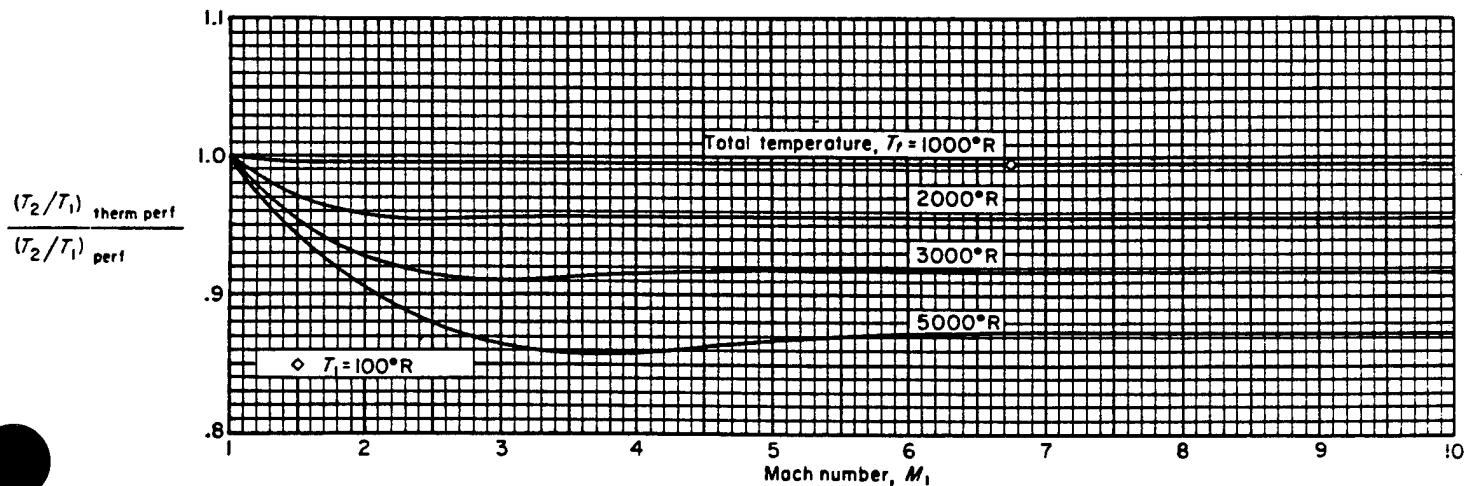


CHART 15.—Effect of caloric imperfections on the static-temperature ratio across a normal shock wave.

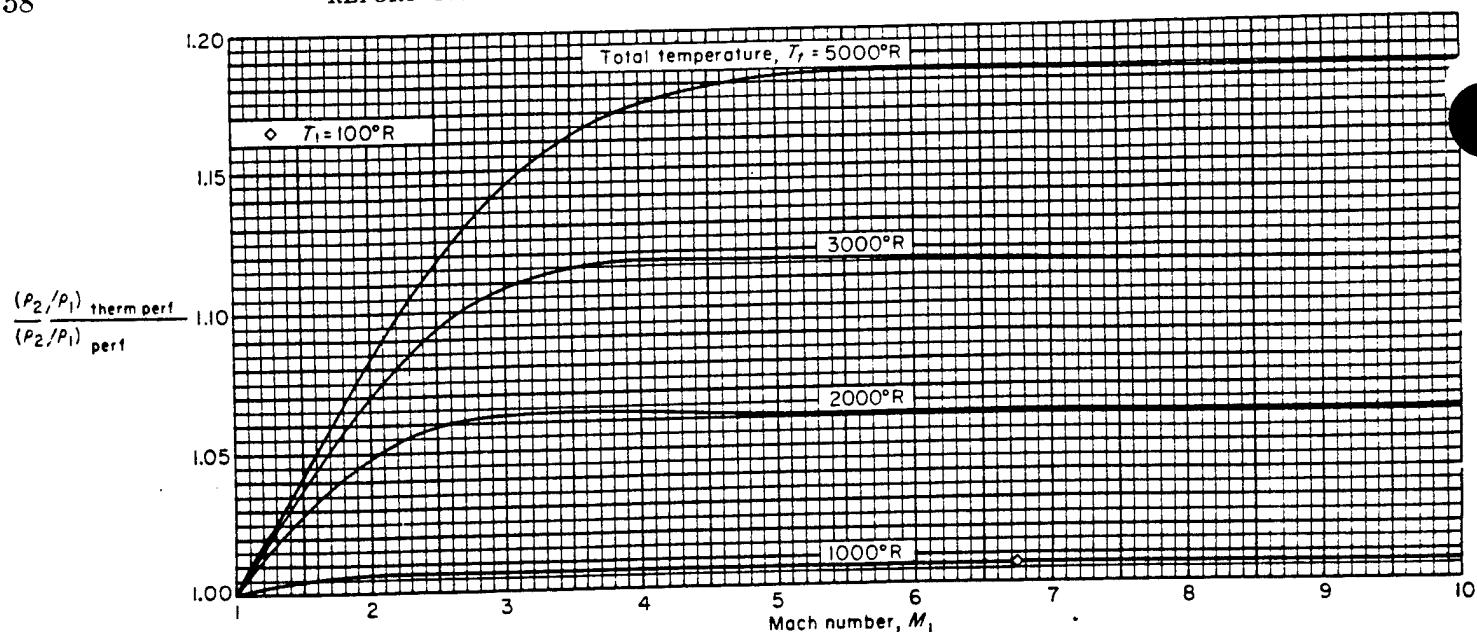


CHART 16.—Effect of calorific imperfections on the static-density ratio across a normal shock wave.

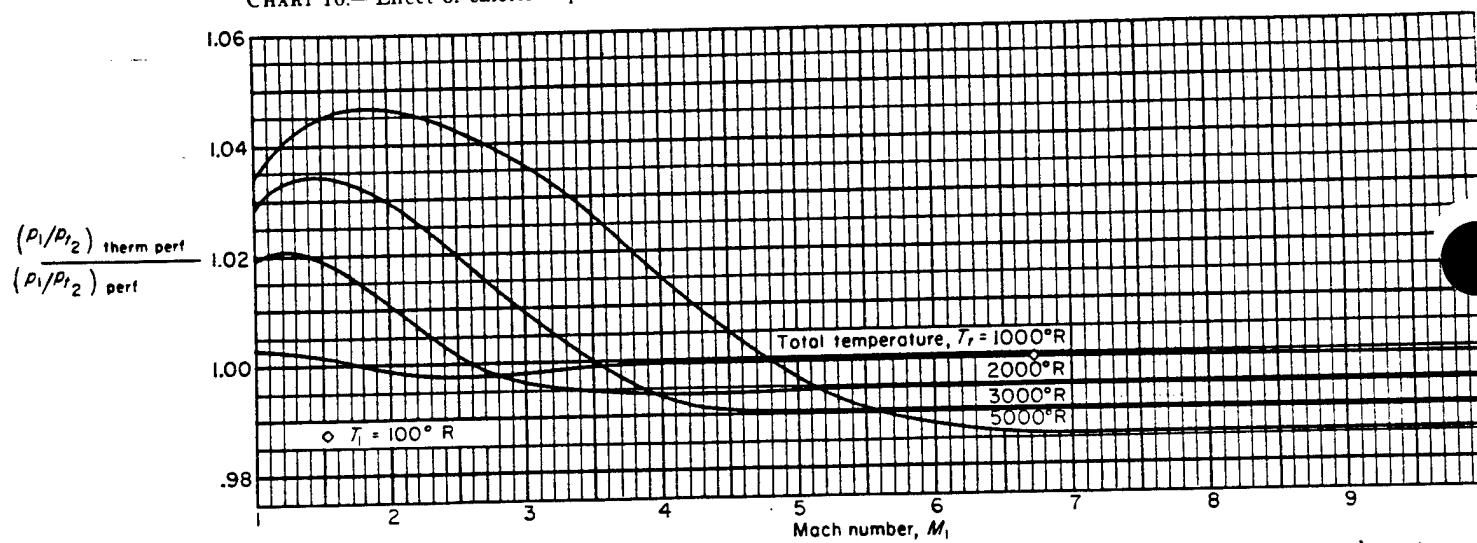


CHART 17.—Effect of calorific imperfections on the ratio of static pressure upstream of a normal shock wave to total pressure downstream.

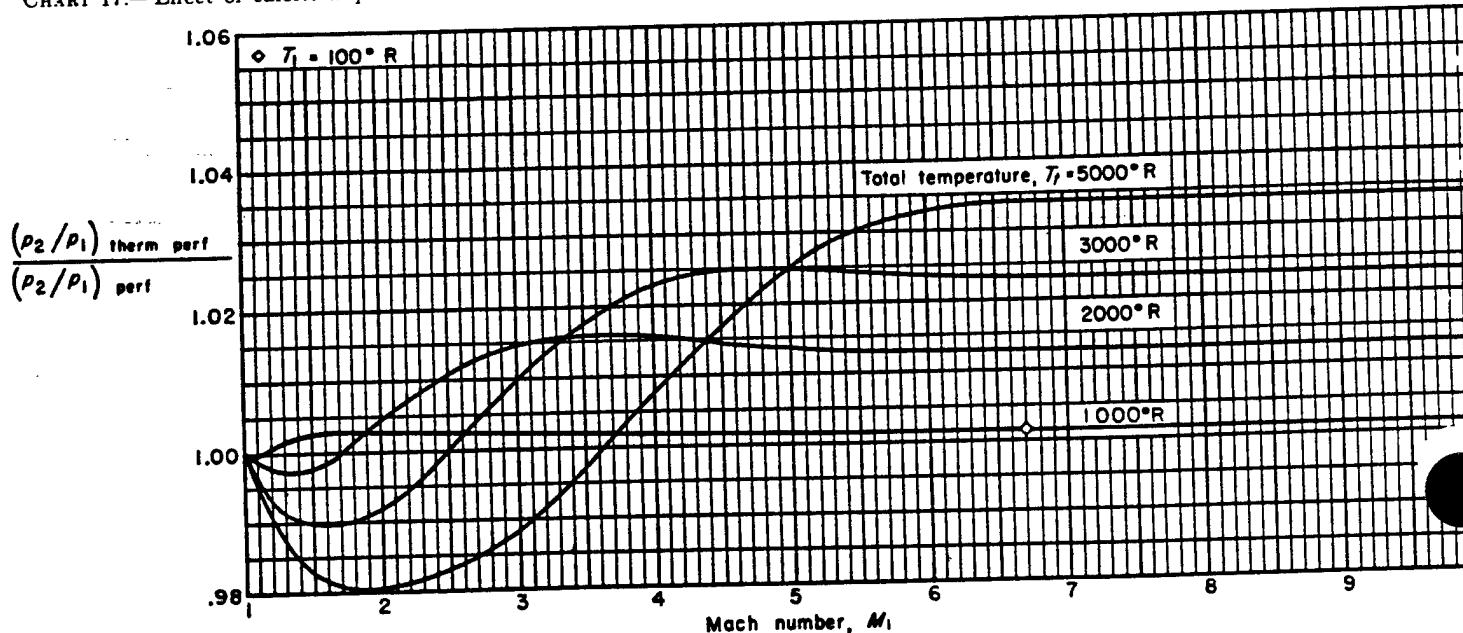


CHART 18.—Effect of calorific imperfections on the static-pressure ratio across a normal shock wave.

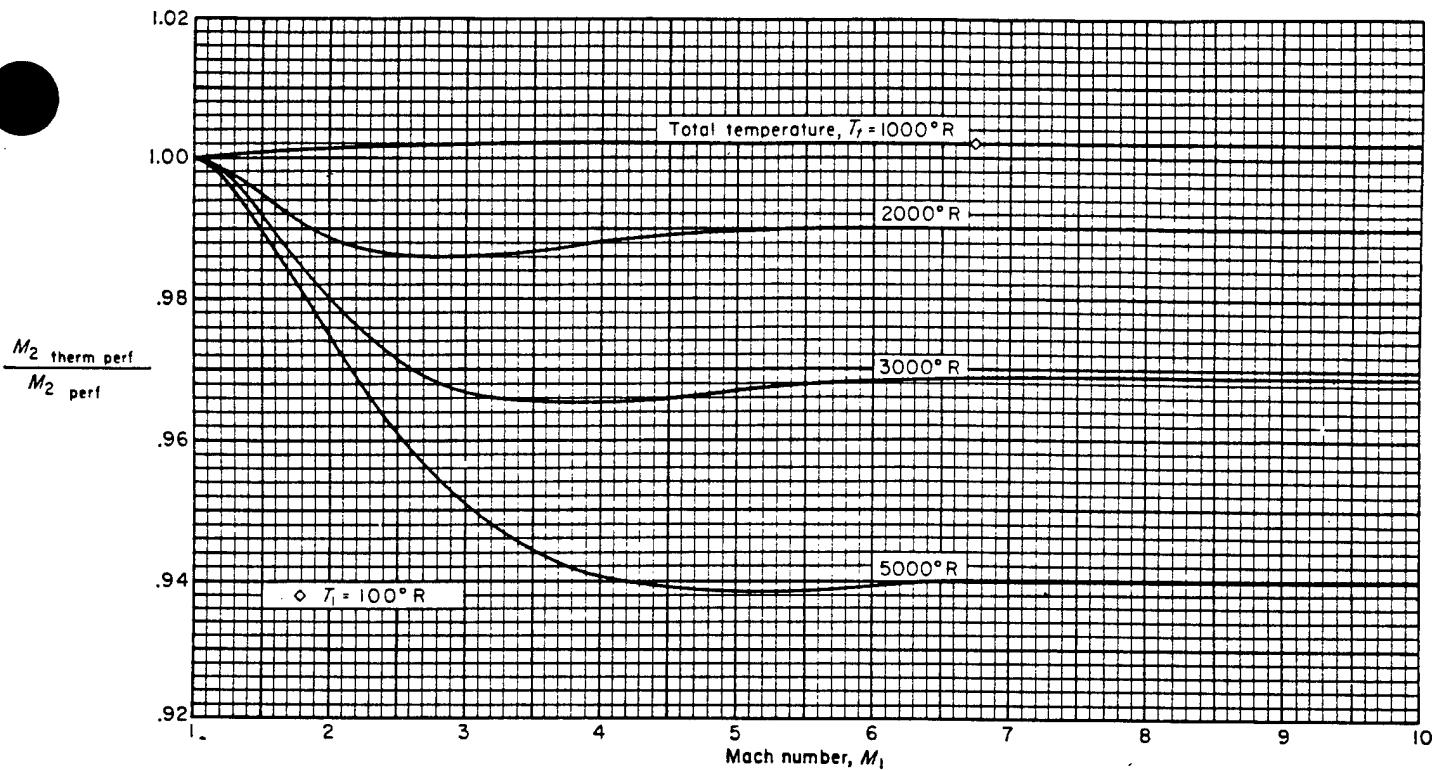


CHART 19.—Effect of caloric imperfections on the Mach number downstream of a normal shock wave.

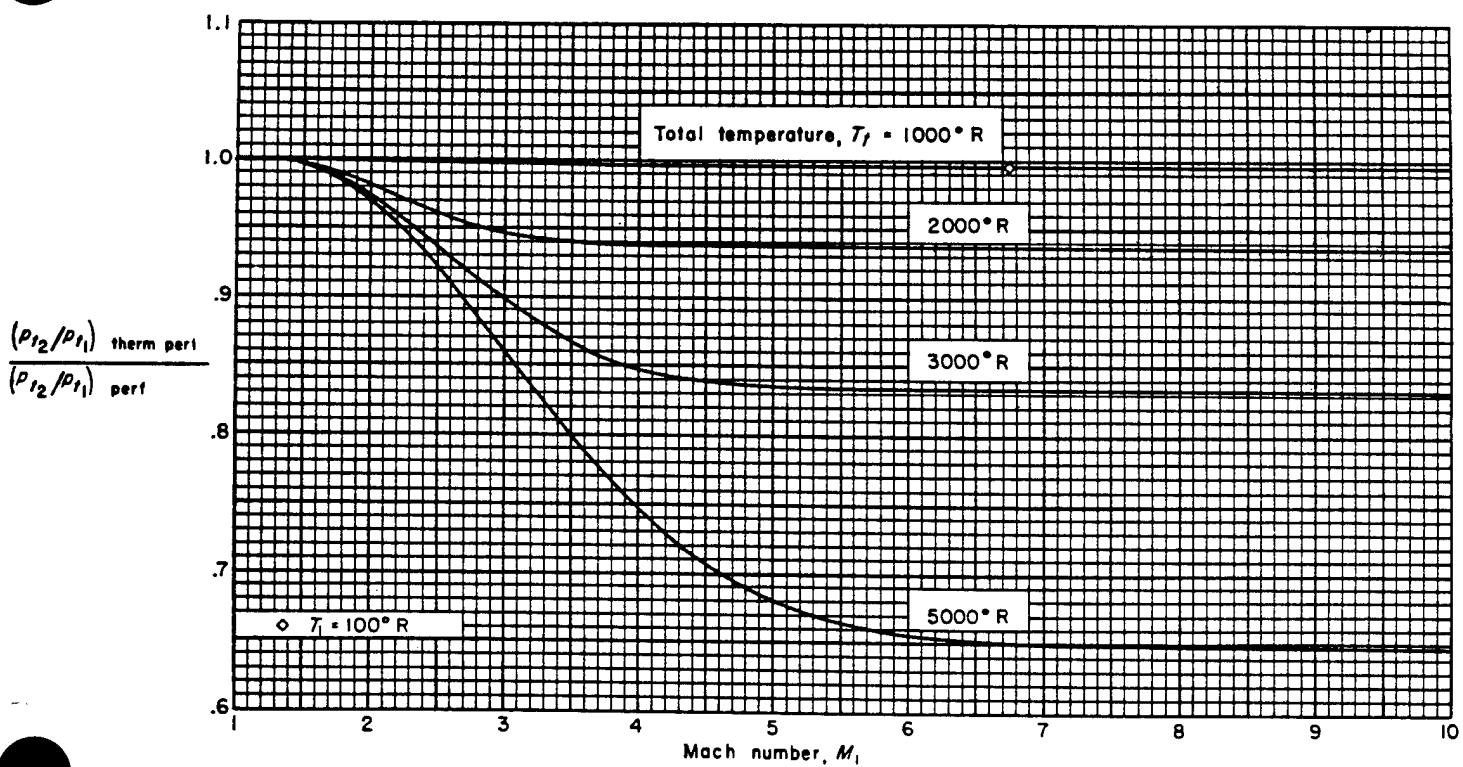


CHART 20.—Effect of caloric imperfections on the total-pressure ratio across a normal shock wave.

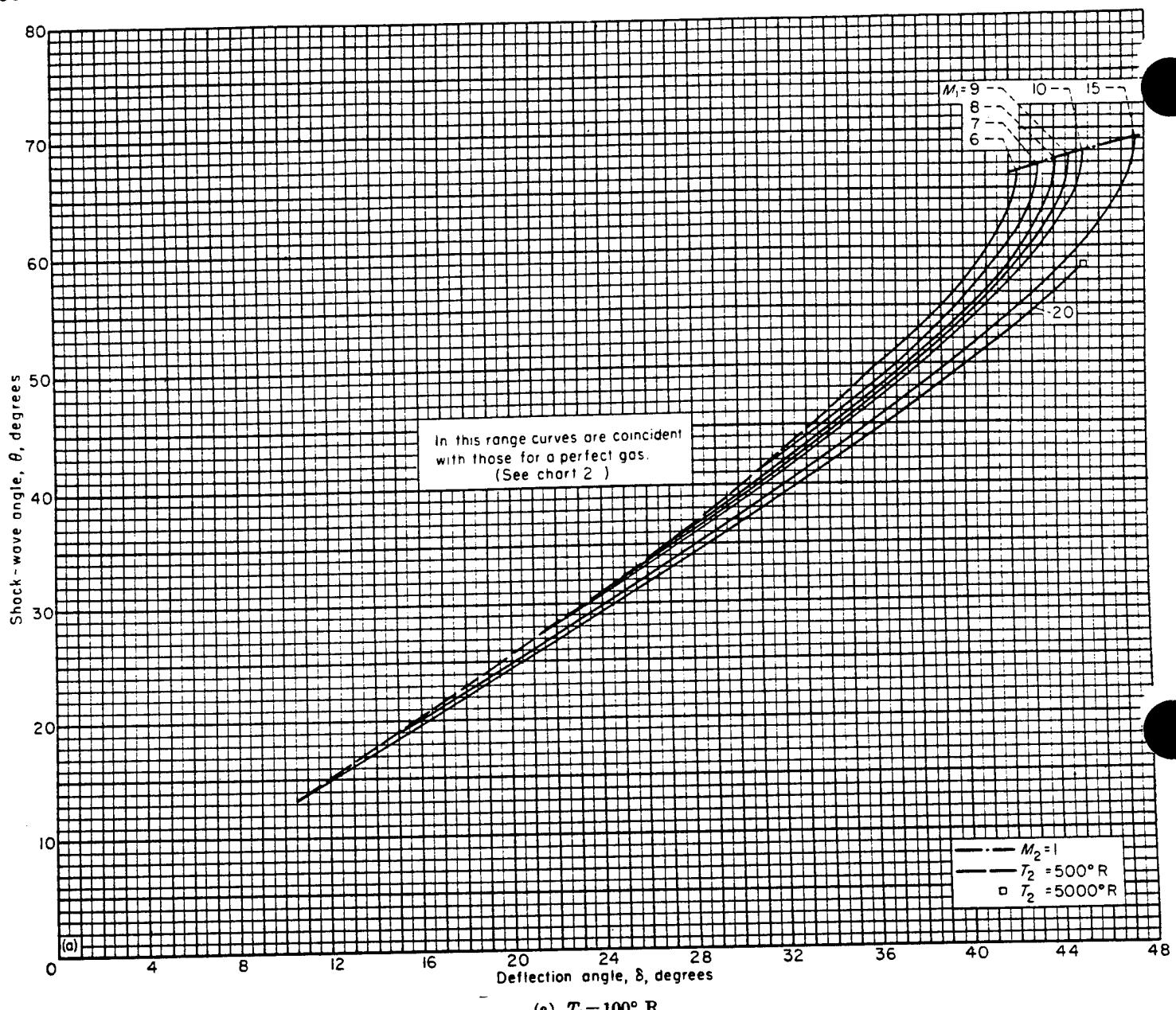
(a)  $T_1 = 100^{\circ}\text{R}$ 

CHART 21.—Effect of caloric imperfections on the variation with flow-deflection angle of the shock-wave angle for a weak oblique shock wave

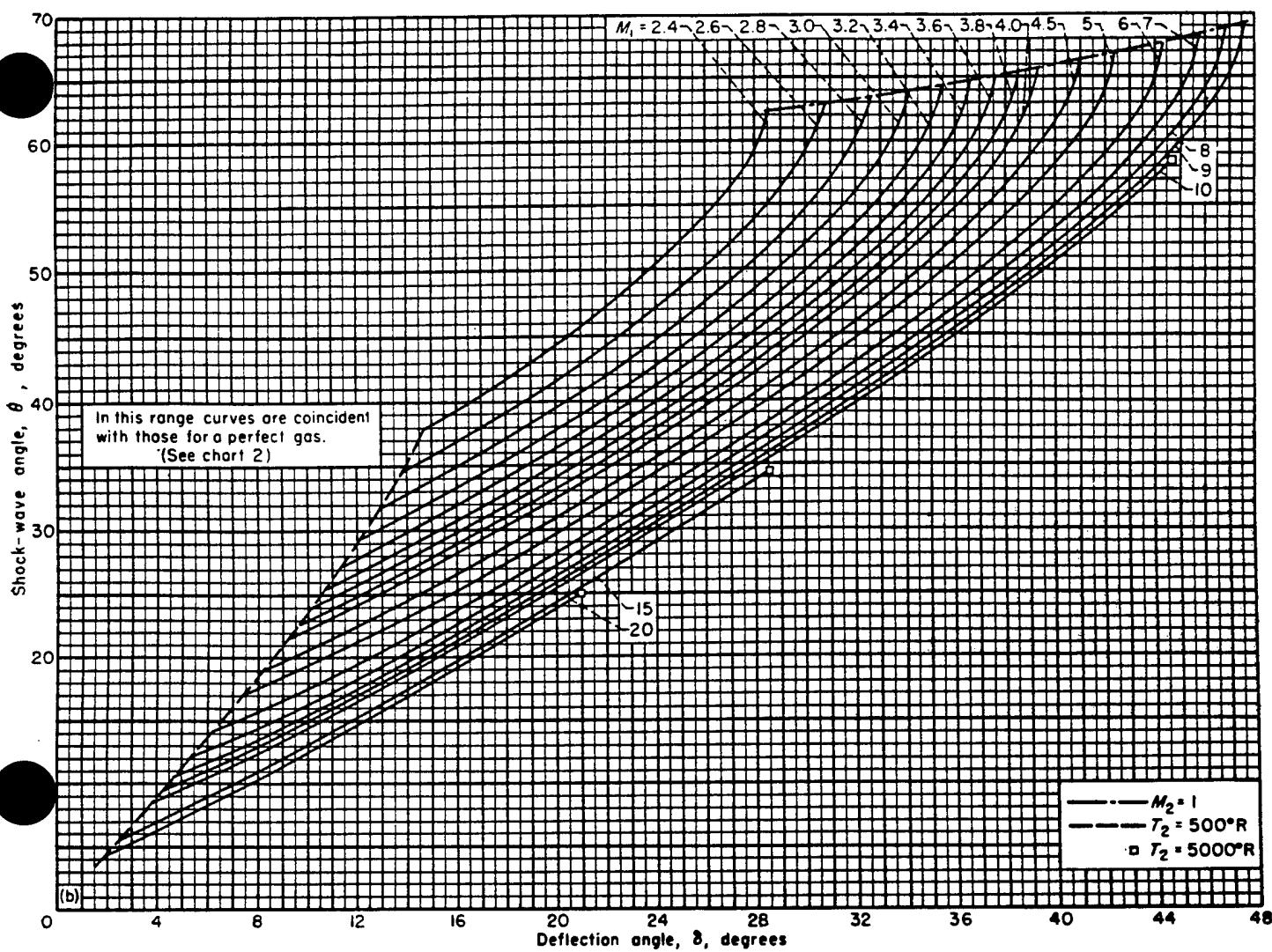
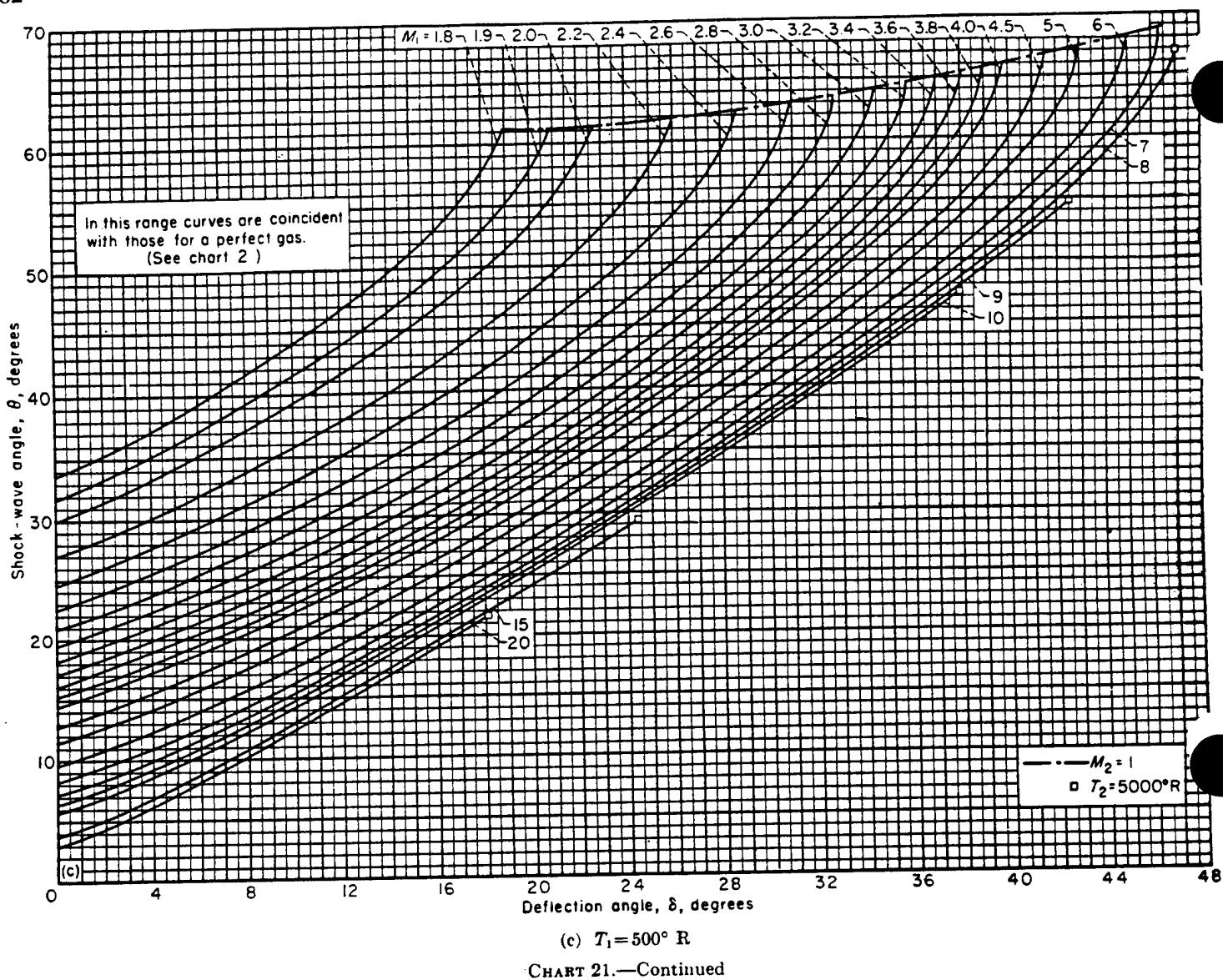
(b)  $T_1=390^{\circ}\text{ R}$ 

CHART 21.—Continued



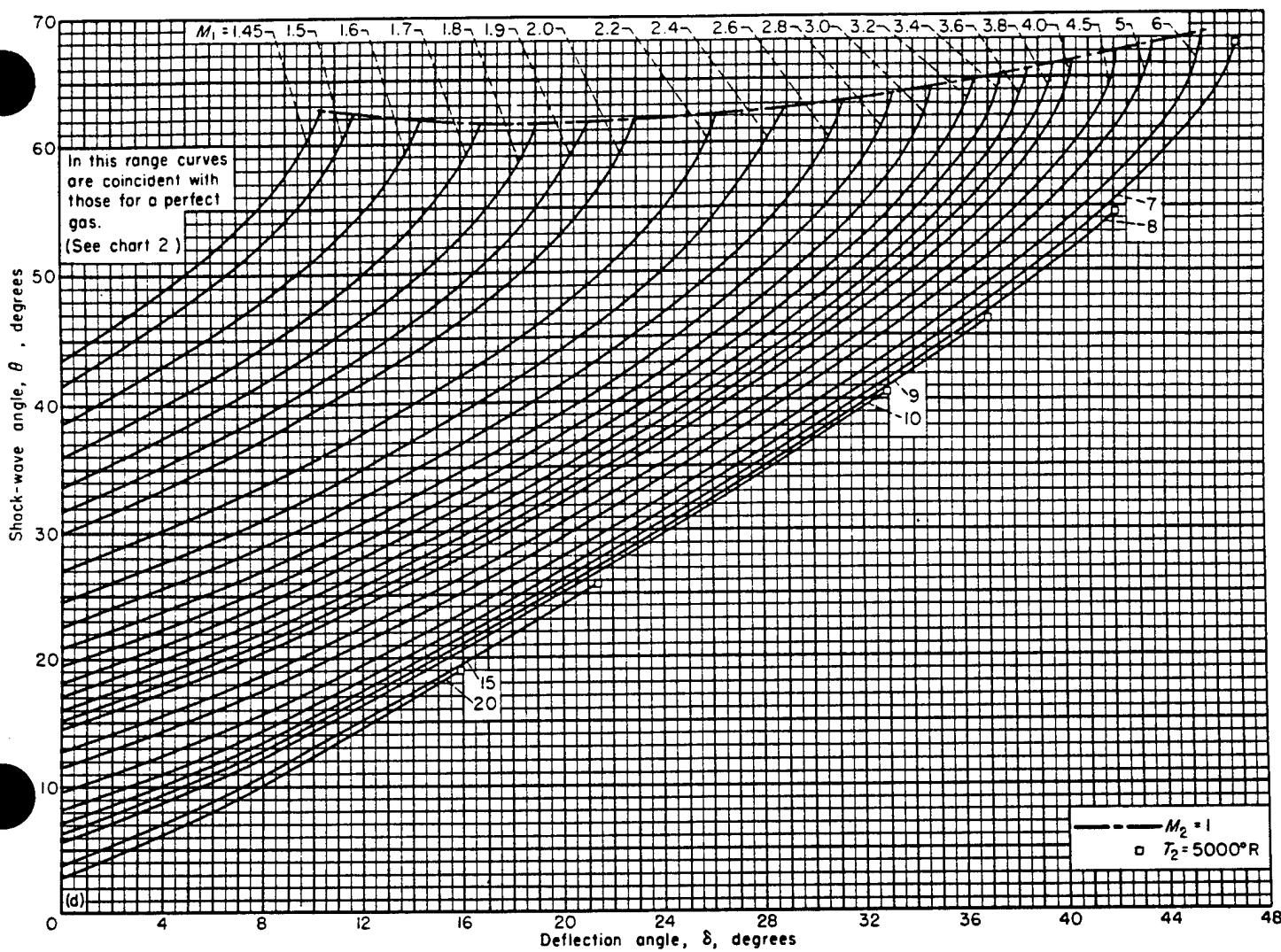
(d)  $T_1 = 630^\circ R$ 

CHART 21.—Concluded

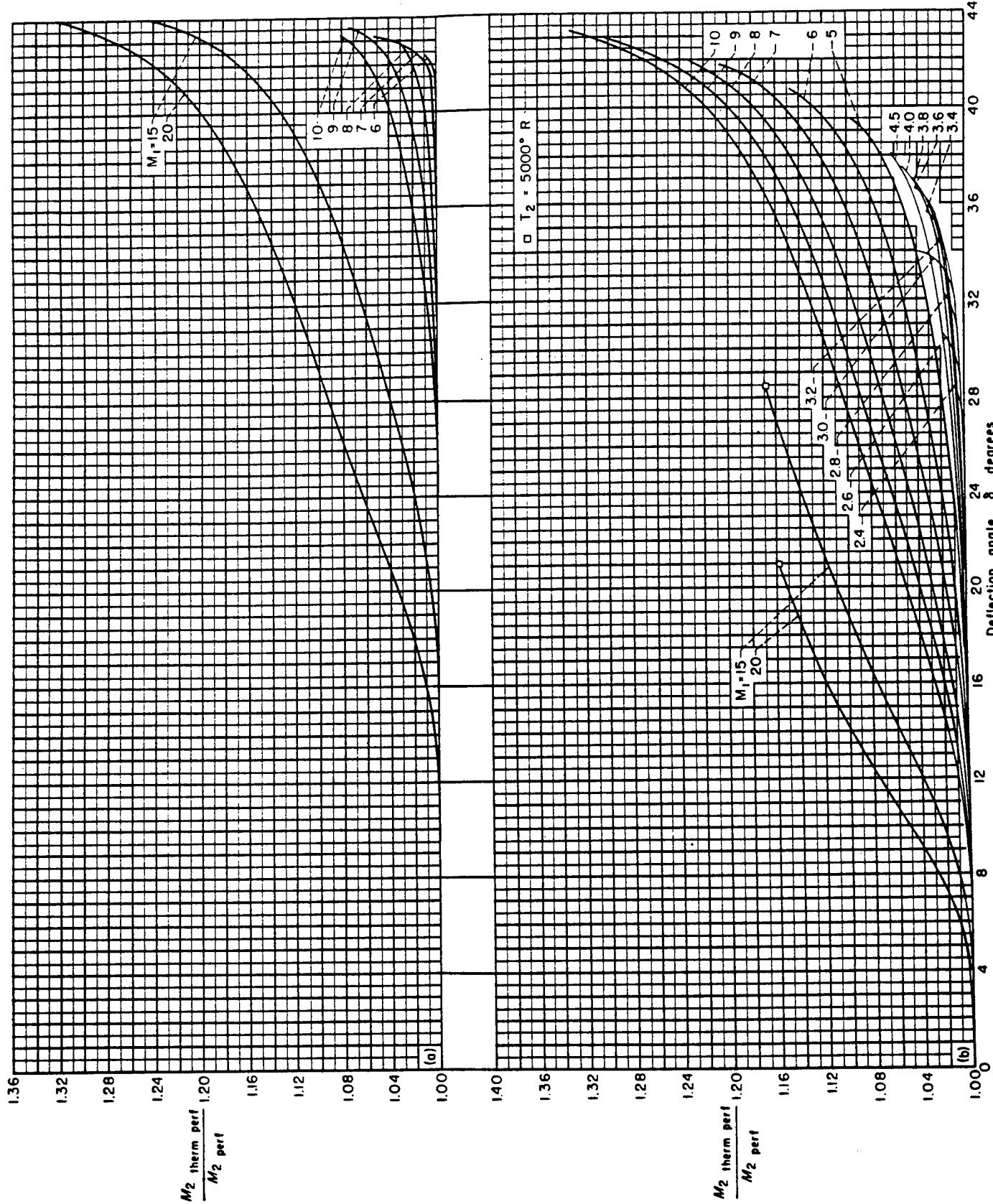


CHART 22.—Effect of caloric imperfections on the variation with deflection angle of the Mach number downstream of a weak oblique shock  
 (a)  $T_1 = 100^\circ \text{ R}$   
 (b)  $T_1 = 390^\circ \text{ R}$

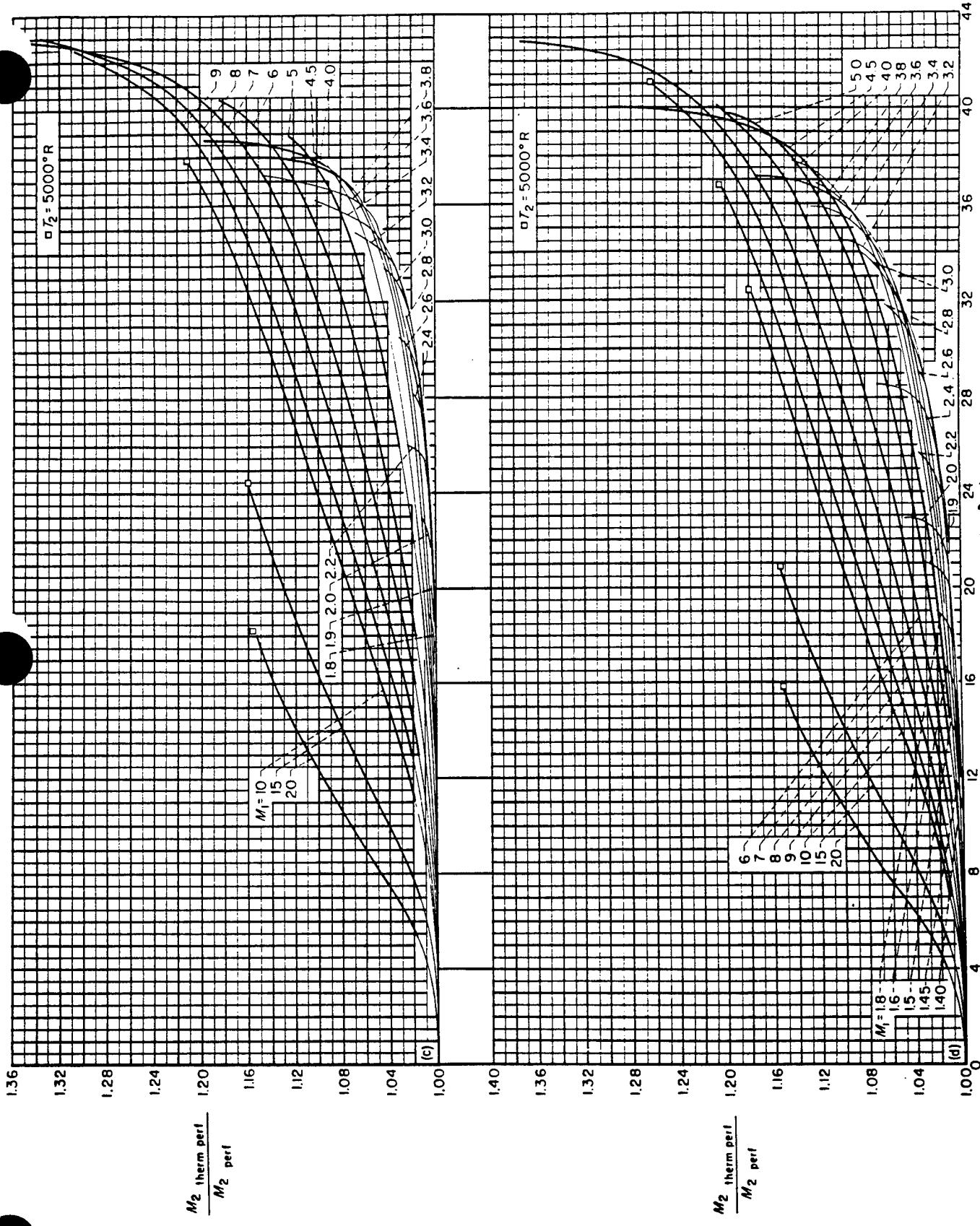


CHART 22.—Concluded

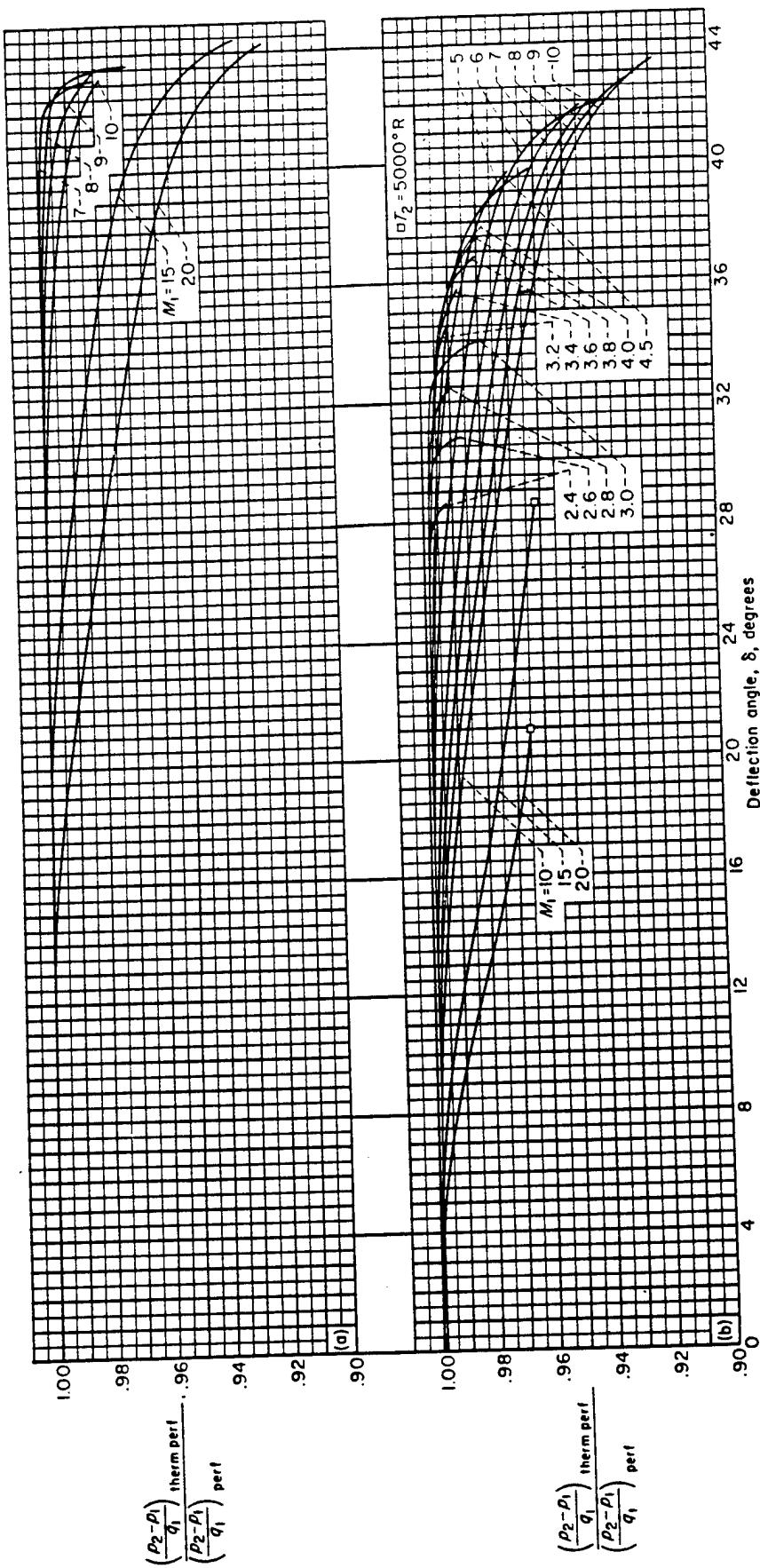


CHART 23.—Effect of calorific imperfections on the variation with flow-deflection angle of the pressure coefficient across a weak oblique shock wave.

- (a)  $T_1 = 100^\circ R$
- (b)  $T_1 = 390^\circ R$

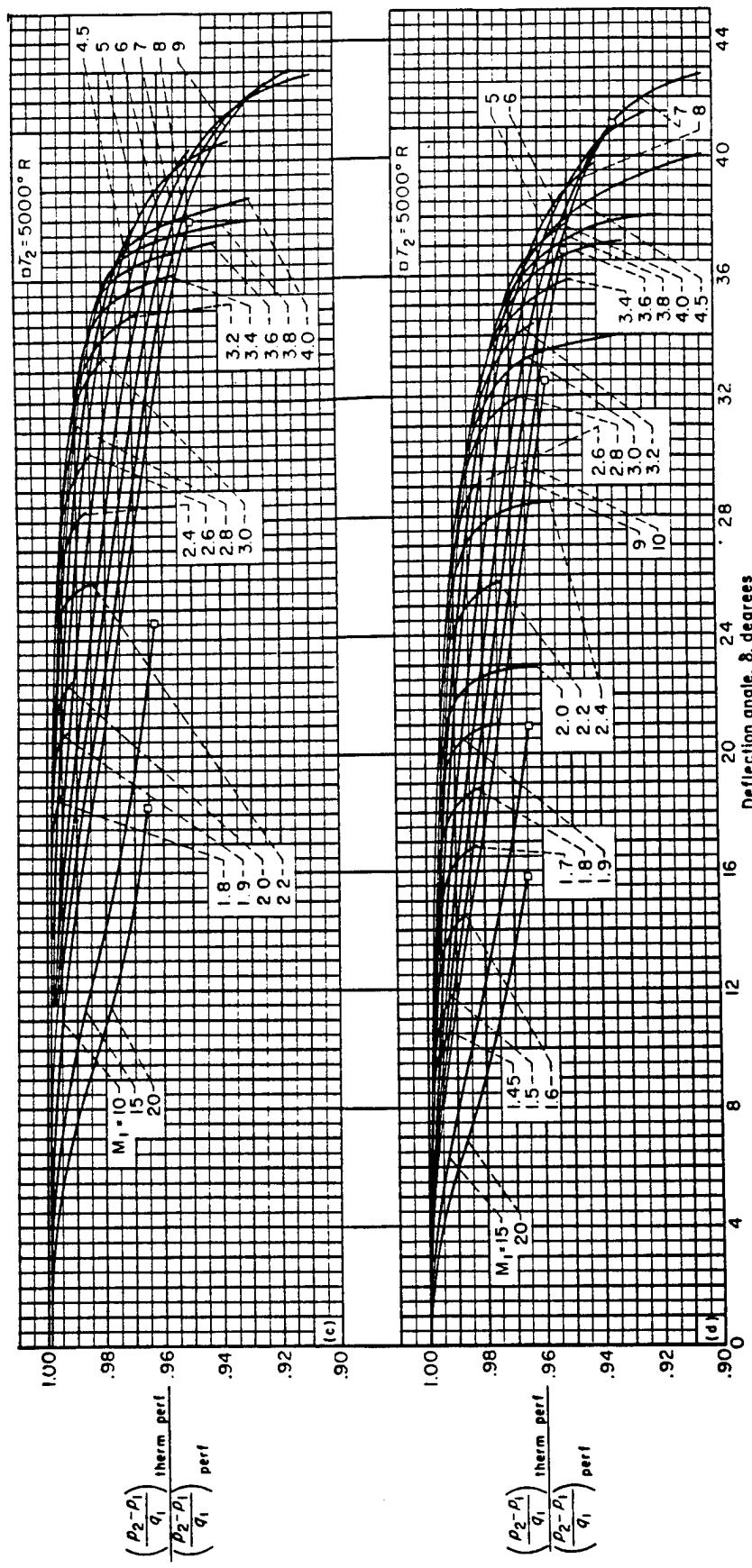


CHART 23.—Concluded  
 (c)  $T_1 = 500^\circ \text{ R}$   
 (d)  $T_1 = 630^\circ \text{ R}$

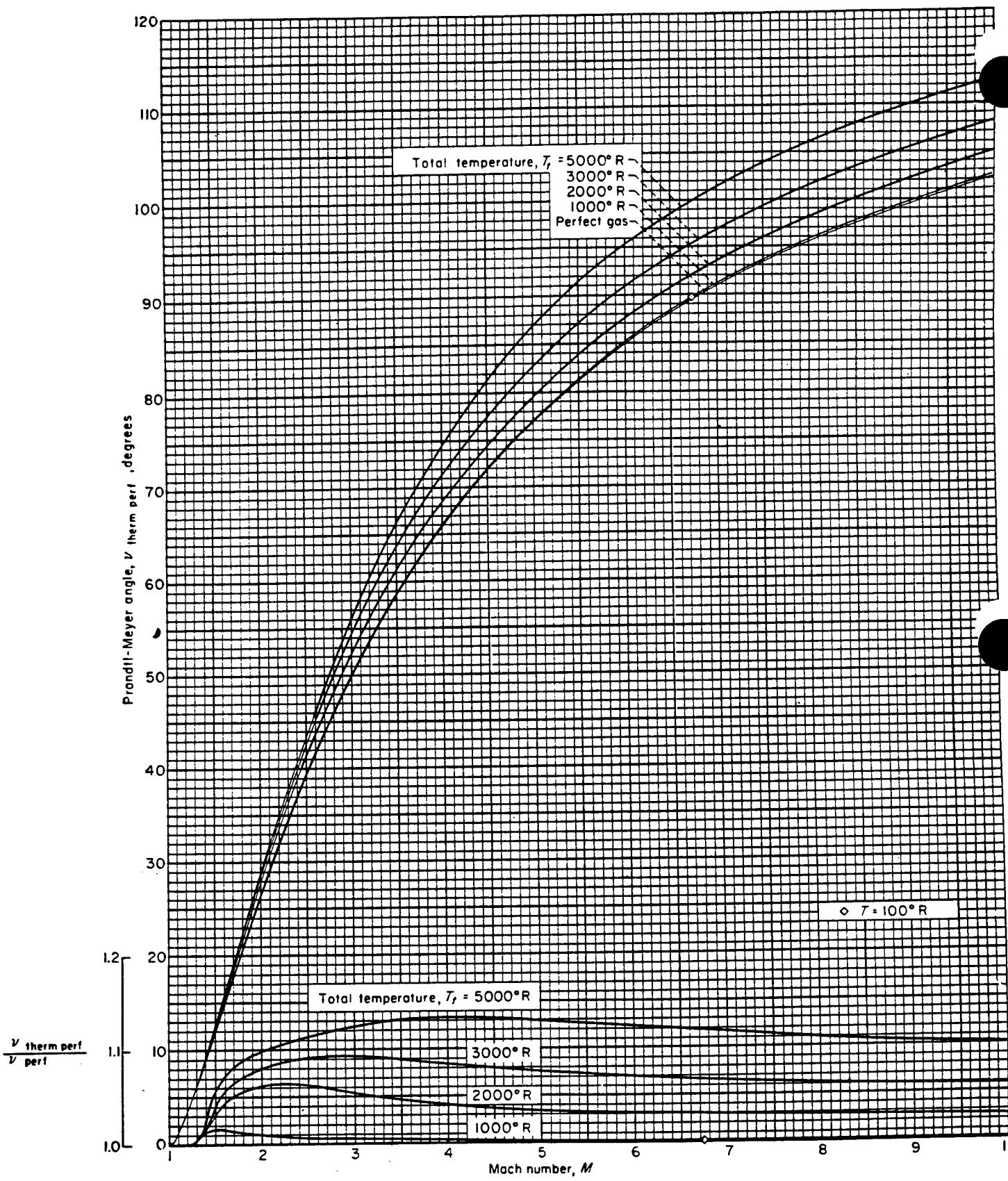


CHART 24.—Effect of caloric imperfections on the Prandtl-Meyer angle.

